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SNAP-8 SIMULATOR LOOP MECHANICAL DESIGN

by Alfred S. Valerino, James C. Wood, and Joseph F. Reznik

Lewis Research Center
Cleveland, Ohio

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SUMMARY

A SNAP-8 system simulation facility was designed, assembled, and tested at the Lewis Research Center. Design flow rates of the three-loop system were 32 000 pounds per hour (4.04 kg/sec) of eutectic sodium-potassium (NaK) in both the primary and heat-rejection loops and 9100 pounds per hour (1.15 kg/sec) of mercury (Hg) in the power loop. The turbine, radiator, and nuclear reactor were simulated. A prototype boiler and condenser were employed. Fluid circulation was obtained by electromagnetic pumps and a centrifugal pump for NaK and Hg, respectively. The Hg loop was operated for approximately 1000 hours; the primary and heat-rejection loops for approximately 2000 hours.

Test results indicated errors in Hg vapor flow rate due to erosion and/or corrosion of the entrance and throat sections of choked venturis. Use of tantalum or the use of a longer gradually sloped entrance section could result in a more reliable venturi design.

The location of spark-plug-type liquid-level indicators in the expansion tanks of the NaK loops resulted in frequent shorting of the indicators. Gas and vacuum lines located atop the tanks were often plugged. Redesign of the expansion tanks using baffles or repositioning of the NaK inlet lines could have avoided these problems.

Metal flexible hoses installed to alleviate thermal expansion of the piping by lateral movement of the hoses were safely employed in the liquid metal loops.

The NaK electric heater employed as the heat source in the primary loop was replaced because of external leaks and electric shorting of the heater-element lead wires. A heater design having direct immersion of the heating elements into the liquid metal would assure lower heating-element wire temperature. Heavier heating-element sheath walls and the use of fuses in the electrical system would provide additional safeguard against electrical burnout.

INTRODUCTION

The advent of the space age has brought into focus the requirement for considerable amounts of electrical power for future use in space. NASA has investigated the design

and development of systems at various power levels. One such investigation is the SNAP-8 Rankine cycle system which is designed to produce electrical power of 35 kilowatts.

The overall SNAP-8 system is being developed on contract, but a multiloop system was assembled at the Lewis Research Center and has been used to provide the contractor with design information and data during steady-state and transient modes of operation.

The Lewis system consisted of three main loops: the primary or heat-source loop utilizing a eutectic mixture of sodium-potassium (NaK) at a flow rate of 32 000 pounds per hour (4.04 kg/sec) in a temperature range of approximately 1100° to 1300° F (866° to 977° K); the power loop which used mercury (Hg) at a flow rate of 9100 pounds per hour (1.15 kg/sec) within the temperature range of 500° to 1300° F (533° to 977° K), and the heat-rejection loop with a flow rate of 32 000 pounds per hour (4.04 kg/sec) of NaK at temperatures between 500° to 700° F (533° to 644° K).

A Hg prototype boiler and a condenser were obtained from the contractor and incorporated into the Lewis system. A NaK electric heater designed to simulate the physical characteristics of a nuclear reactor was employed as the heat source. The turbine and radiator were also simulated. Commercially available electromagnetic pumps (EM pumps) and a centrifugal pump were used to circulate the NaK and Hg, respectively. Tests were conducted to obtain component and system performance during steady-state and transient modes of operation.

The SNAP-8 system tested at Lewis is described herein, and design information on simulated components and test support equipment is provided. In addition, problem areas are noted and recommendations are presented for avoiding similar problems in liquid metal loops.

DESCRIPTION OF FACILITY

The simulated SNAP-8 system consisted of a primary NaK loop, a Hg loop operating on a Rankine cycle, and a heat-rejection NaK loop. An auxiliary purification loop to remove the oxides from the NaK was provided. Vacuum systems for the Hg and NaK loops, as well as inert gas systems (argon and nitrogen), and a coolant air system were incorporated in the facility design. A schematic of the liquid metal loops is presented in figure 1.

Facility Housing

An artist's conception of the simulated SNAP-8 system and a plan view of the facility are presented in figure 2. The liquid metal portion of the system was enclosed within the

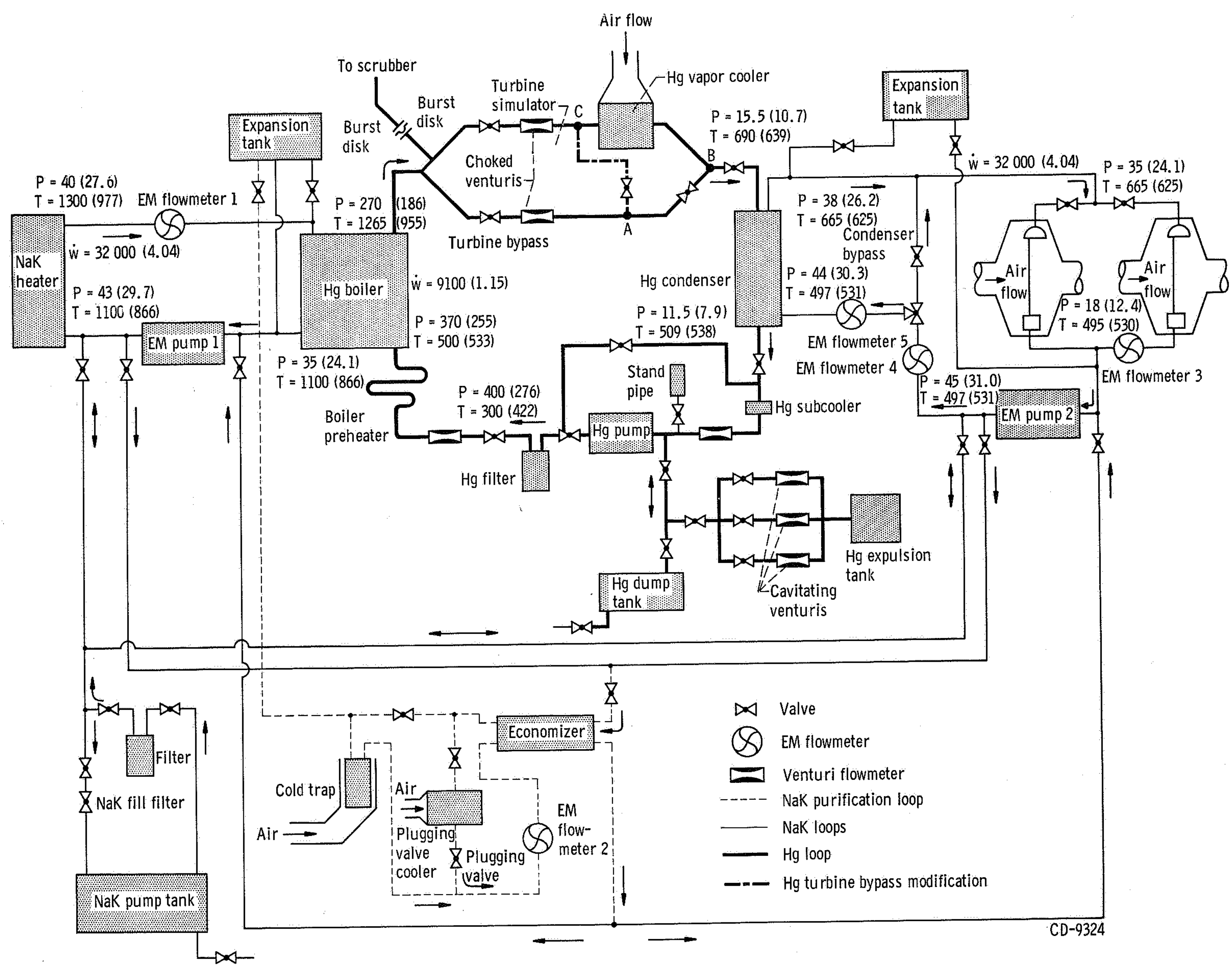
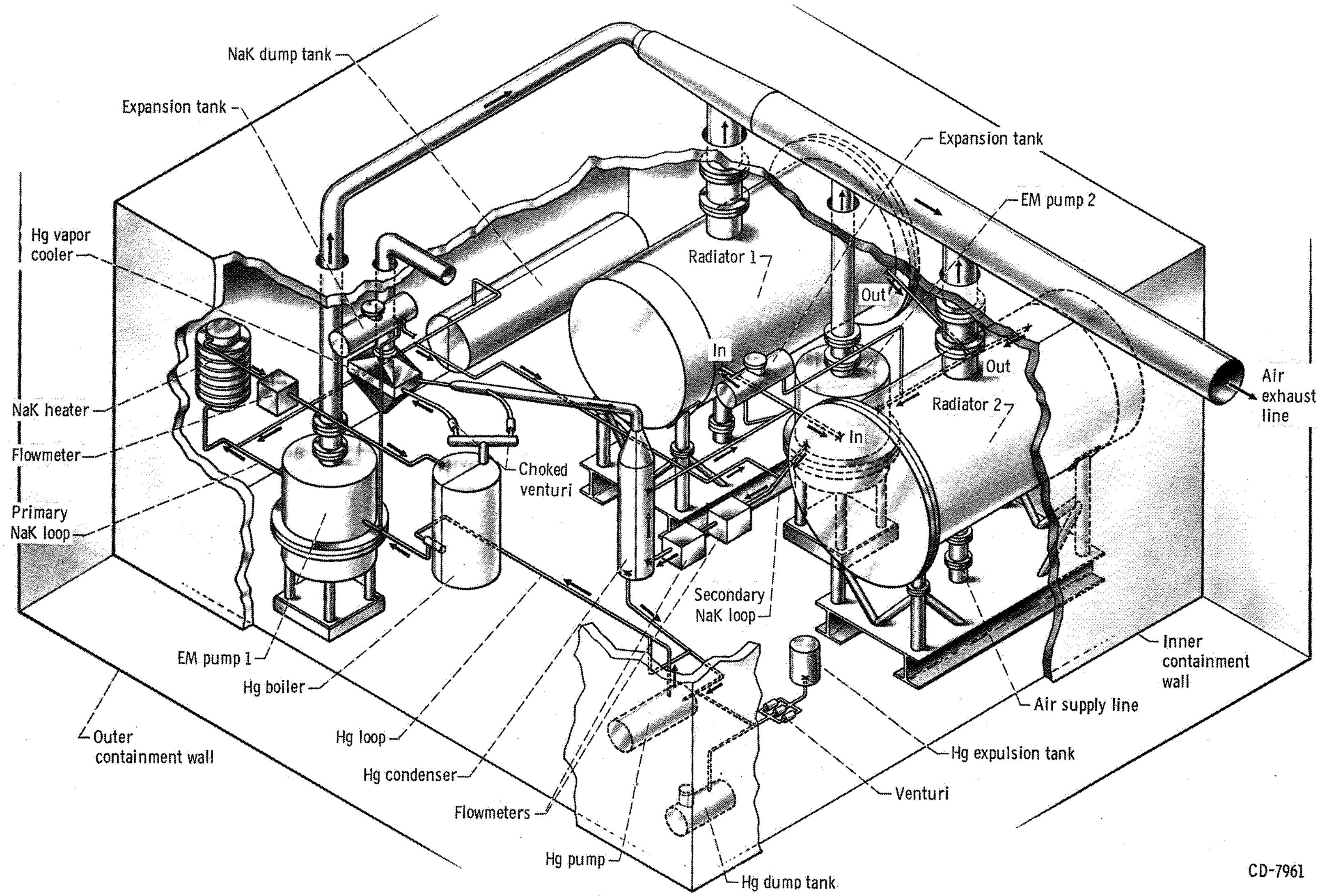
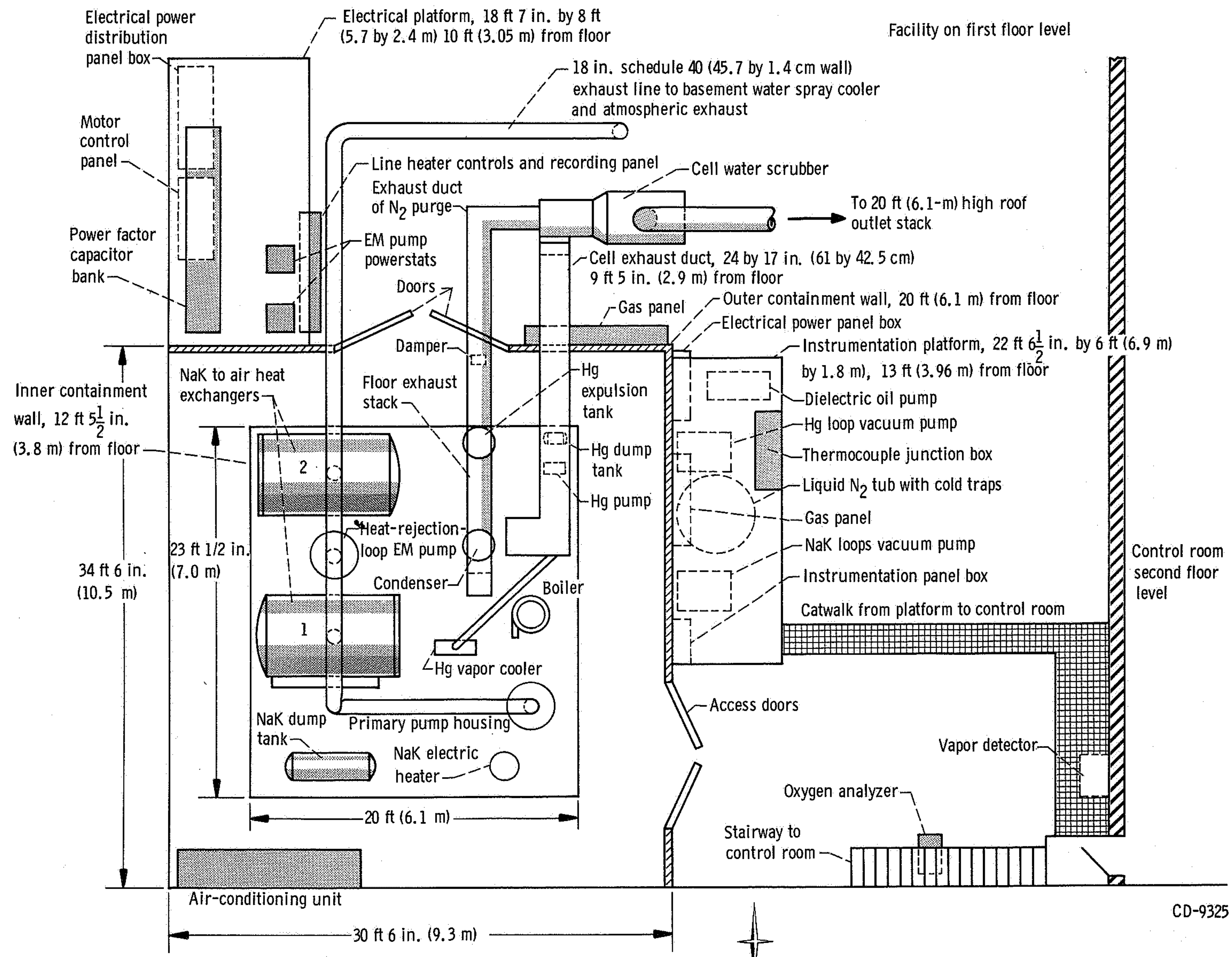


Figure 1. - SNAP-8 schematic diagram. (Absolute pressure, P, psia (N/cm^2 abs); temperature, T, °F (°K); flow rate, $\dot{w}$, lb/hr (kg/sec).)



(a) Artist's conception.

Figure 2. - SNAP-8 experimental loop.



(b) Plan view of facility.

Figure 2. - Concluded.

two containment housings. The purpose of the inner housing was to contain any liquid metal spilled as a result of a leak. The outer housing served as a containment for the nitrogen atmosphere maintained inside during loop operation. The inner housing was approximately 20 by 23 by $12\frac{1}{2}$ feet high (6.1 by 7.0 by 3.8 m high) and was built entirely of steel. It was constructed with a floor pan, hinged removable doors with observation ports, and a removable ceiling.

The outer housing ($30\frac{1}{2}$ by $34\frac{1}{2}$ by 20 ft high (9.3 by 10.5 by 6.1 m high)) consisted of a steel framed metal-clad wall and ceiling. Two sets of access doors with observation ports were incorporated in the outer housing, as shown in figure 2(b). The steel frame of the outer housing wall and the ceiling of the test cell were utilized to support a platform containing electrical equipment and a platform with instrumentation equipment. A walkway interconnected the instrumentation platform with the control room on a second-floor level (fig. 2(b)).

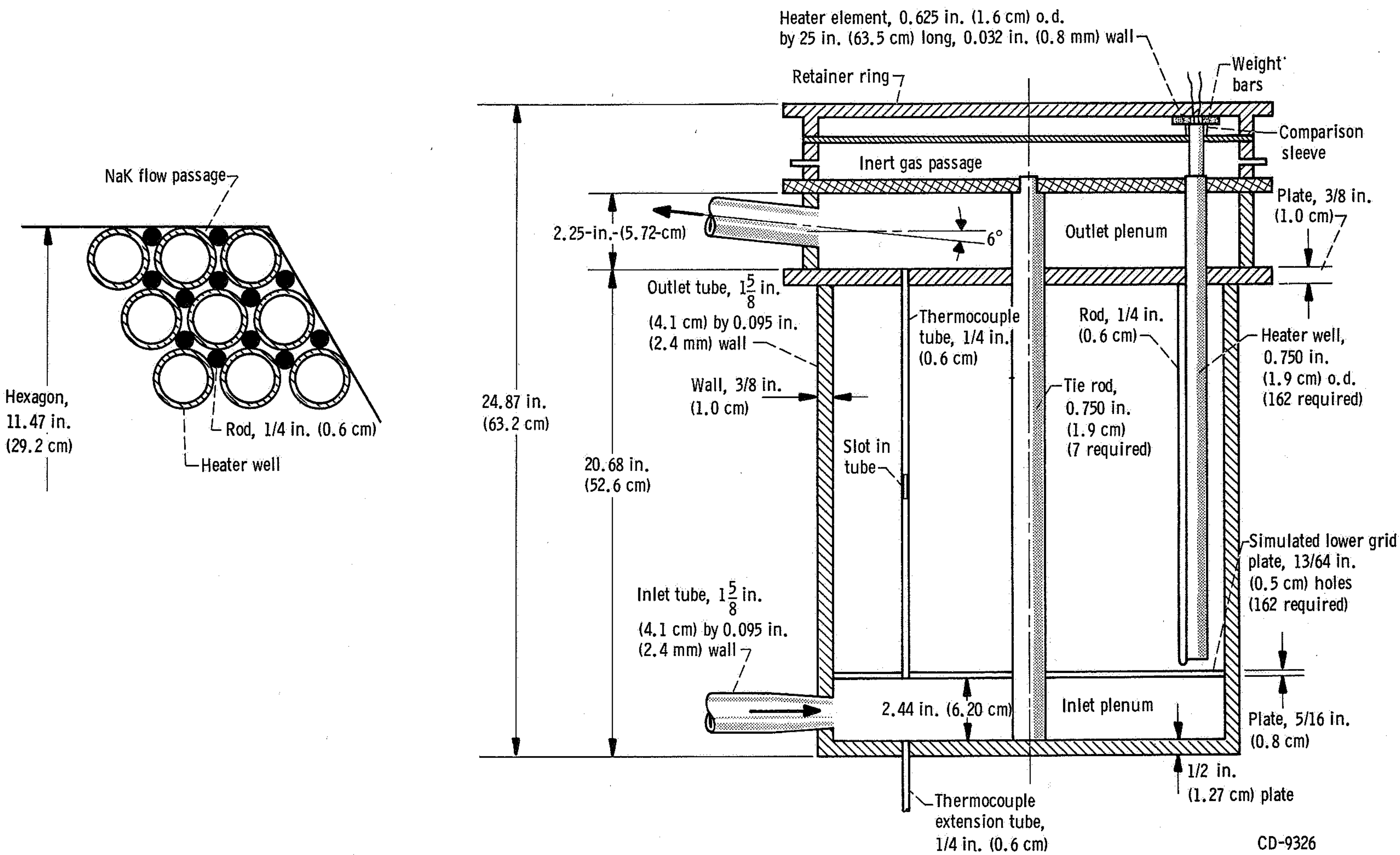
Liquid Metal Loops

Primary NaK loop and fill-dump system. - The primary loop consisted of an EM pump, a NaK electric heater, an EM flowmeter, a Hg boiler, and an expansion tank. The loop design parameters are shown in figure 1.

The EM pump was an alternating conduction type with an electric-motor-driven autotransformer having a 480-volt single-phase 60-cycle electrical input and a 540-volt 112-ampere maximum output. The protective cage of the pump was removed so that the pump support frame could be bolted to a 48-inch (122 cm) cylindrical steel housing. The housing was welded to the metal floor pan of the inner containment, thus fixing the location of the pump. Air was supplied to the pump housing to cool the pump coil.

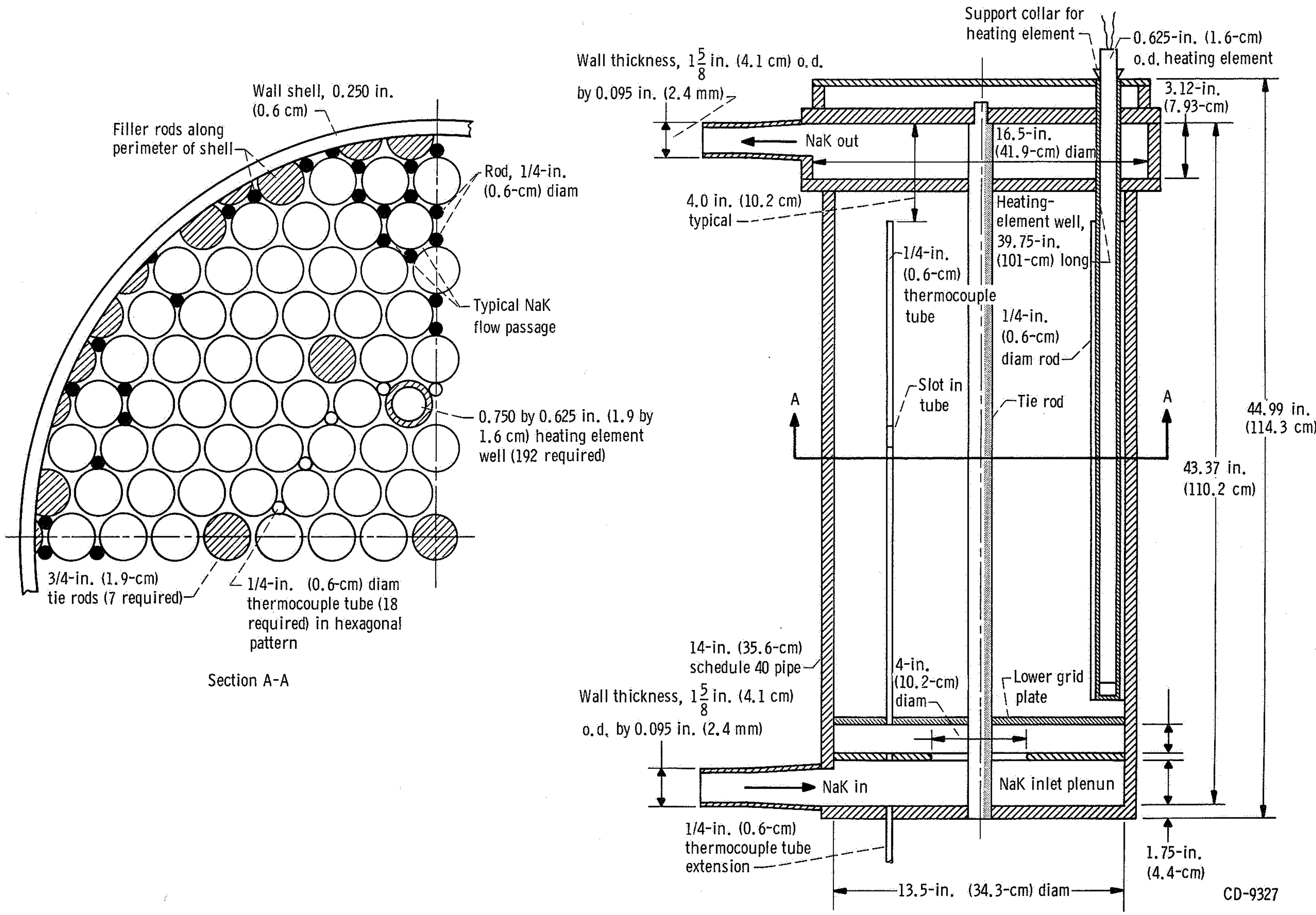
The NaK electric heater was located downstream of the EM pump. The original design concept of the NaK electric heater (fig. 3(a)) was to be as physically similar to the SNAP-8 reactor as possible, with the exception that electric heater elements be used as the heat source instead of nuclear fuel rods. The original design, rated at 515 kilowatts, utilized 162 circular type heater elements immersed in stainless-steel wells which were alined in a hexagonal pattern. Each heater element was rated at 3180 watts at 230 volts.

A backup heater (fig. 3(b)) was employed in the primary loop after operational difficulties were encountered with the original heater. The heater was rated at 552 kilowatts with each of the 192 circular heating elements rated at 2875 watts at 230 volts. The backup heater was designed to be more reliable than the original heater. This was accomplished at the expense of a heater design closely resembling the nuclear reactor. A description of the heaters used in conjunction with an analog computer to simulate the nuclear reactor are presented in reference 1.



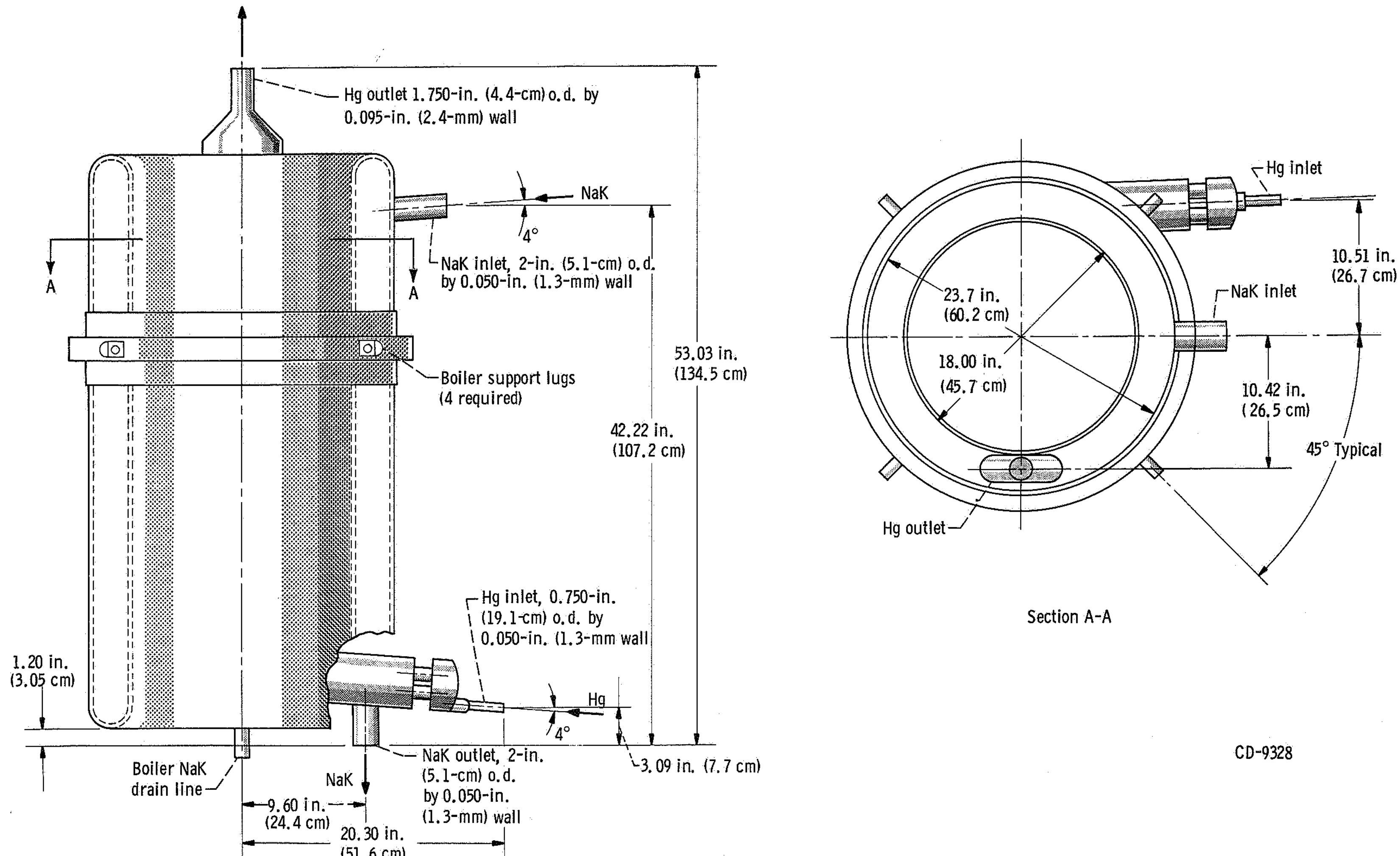
(a) Original design.

Figure 3. - NaK electric heater.



(b) Backup design.

Figure 3. - Concluded.

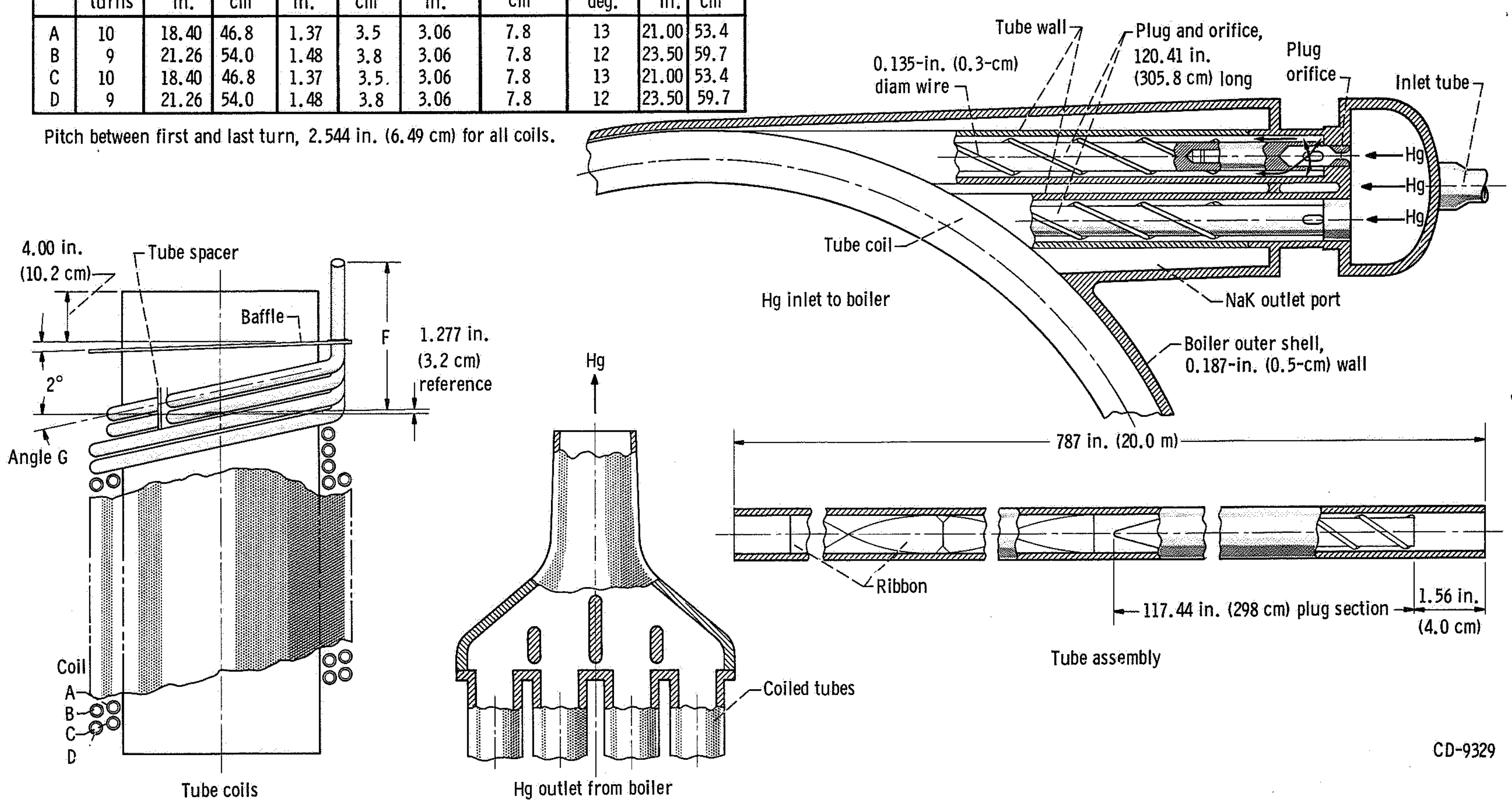


(a) Overall.

Figure 4. - Mercury boiler.

Coil	Number of turns	Diameter of coil		Height of 180° of first turn		Height of first turn		Angle, G, deg.	Distance, F	
		in.	cm	in.	cm	in.	cm		in.	cm
A	10	18.40	46.8	1.37	3.5	3.06	7.8	13	21.00	53.4
B	9	21.26	54.0	1.48	3.8	3.06	7.8	12	23.50	59.7
C	10	18.40	46.8	1.37	3.5	3.06	7.8	13	21.00	53.4
D	9	21.26	54.0	1.48	3.8	3.06	7.8	12	23.50	59.7

Pitch between first and last turn, 2.544 in. (6.49 cm) for all coils.



(b) Details.

Figure 4. - Concluded.

Flow rates in the primary loop were determined by an EM flowmeter located between the NaK heater and the Hg boiler. A description of the flowmeter is presented in the instrumentation section, Flowmeters.

The Hg boiler (fig. 4(a)) was designed and fabricated by the SNAP-8 system contractor. It was a cross-counter-flow heat exchanger employing four helically coiled AISI 505 (9Mo-1Cr) Hg tubes within an AISI 316 stainless-steel toroidal shell which served as the NaK passageway.

Liquid Hg entered the boiler through a plenum which accommodated metering orifices for each of the four Hg tubes (fig. 4(b)). After the liquid Hg passed through the orifices, the flow was restricted by wire wrapped plugs (approx 120 in. (305 cm) long) which were inserted into the AISI 505 tubing. A description of the Hg boiler and its performance are discussed in reference 2.

An expansion tank (fig. 5) to accommodate the increase in NaK volume with increasing loop temperature was connected to the loop between the Hg boiler and the pump. The line also provides a means to control pump inlet pressure. The expansion tank, the highest point in the system, was located approximately $12\frac{1}{2}$ feet (3.8 m) from floor level. A pneumatically operated on-off valve was utilized to connect the NaK inlet port of the Hg boiler (the high point in the primary loop) to the expansion tank. This line was required to remove any entrapped gases from the elevated portions of the primary loop during the NaK fill process. The valve was maintained in the closed position during operation of the primary loop.

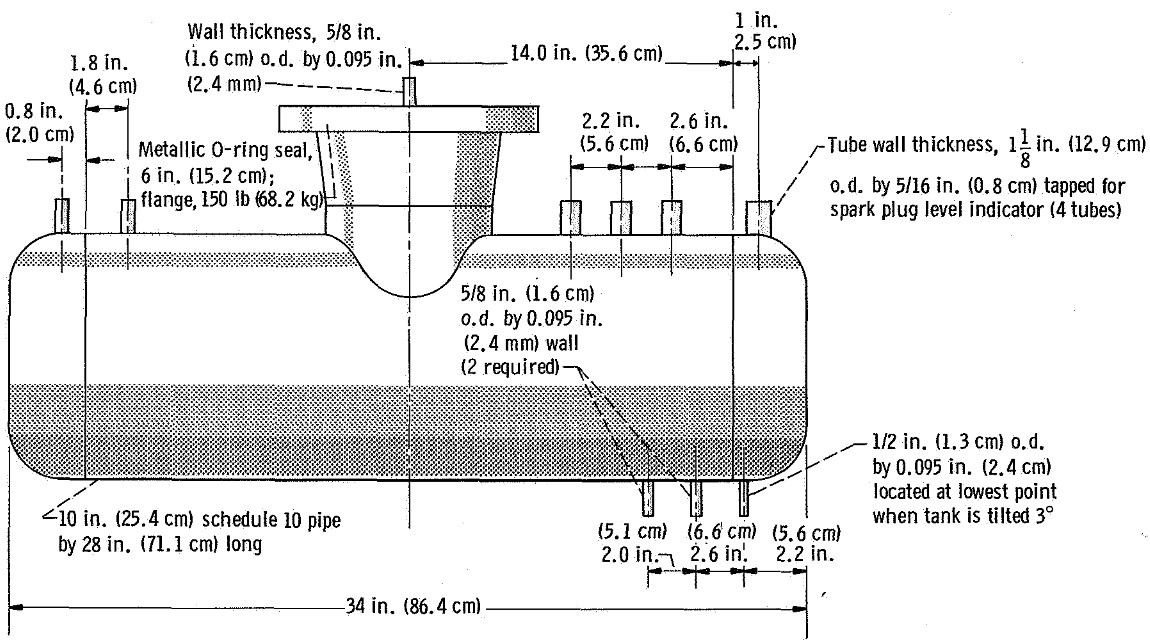


Figure 5. - NaK expansion tank. All joints and tubes are inert arc welded. All material AISI 316 stainless steel.

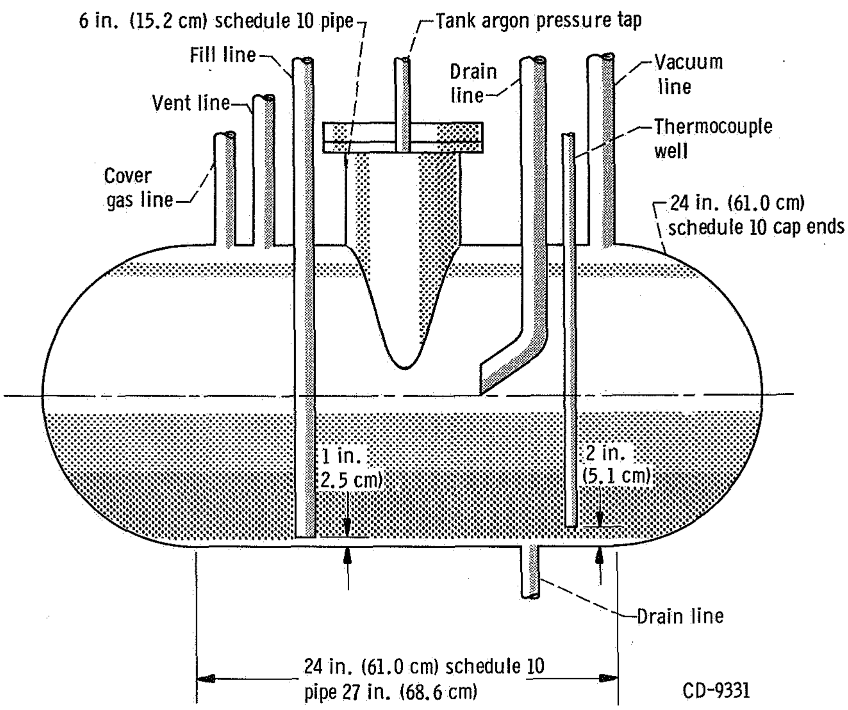


Figure 6. - NaK dump tank.

Filling and dumping of the primary loop was accomplished through a line connecting the loop to the large dump tank shown in figure 6. This tank also served the heat-rejection loop. Figure 1 shows how the lines were connected between the loops and the dump tank. The manually operated valves were used to isolate the NaK in the dump tank as a safety precaution when the system was shut down.

To fill the loop, the NaK in the dump tank was pressurized to force NaK into the loop. During filling, the NaK flowed through a 20-micron AISI 316 stainless sintered porous filter. During dumping, the NaK flowed directly into the dump tank.

The material of all the tubing employed was AISI 316 stainless steel. All tubing sizes used in the loops are shown in table I. Transition pieces were used to connect the components as required. All lines were sloped a minimum of 3° to accomplish adequate draining of the loop.

The EM pump and NaK dump tank were the only fixed components in the loop. The valves, heater, flowmeter, boiler, and expansion tank were supported by cables attached to the inner containment housing structural ironwork. Attachment was made at the top of the component thus allowing the component to expand downward with increasing temperature. Piping expansion was accommodated by single-ply flexible hoses located on both sides of the EM pump and in the dump and fill lines. Because of the relatively small diameter and long length of the tubing connecting the expansion tank to the loop, the tubing flexure was sufficient to avoid large flexure stresses during temperature changes. A

TABLE I. - PIPING SIZES

Location	Size	
	in.	cm
NaK loops:		
Dump lines	$1\frac{5}{8}$ o.d. by 0.095	4.1 o.d. by 0.2
Fill filter line	$\frac{5}{8}$ o.d. by 0.095	1.6 o.d. by 0.2
Expansion tanks to loops	$\frac{5}{8}$ o.d. by 0.095	1.6 o.d. by 0.2
Rest of primary loop	$1\frac{5}{8}$ o.d. by 0.095	4.1 o.d. by 0.2
Rest of heat-rejection loop	$1\frac{3}{4}$ o.d. by 0.095	4.5 o.d. by 0.2
NaK purification loop	$\frac{5}{8}$ o.d. by 0.095	1.6 o.d. by 0.2
Hg loops:		
Dump-fill system	$\frac{1}{2}$ o.d. by 0.095	1.3 o.d. by 0.2
Pump to boiler and pump bypass	$\frac{3}{4}$ o.d. by 0.065	1.9 o.d. by 0.2
Boiler to vapor cooler	1 Schedule 10 pipe	3.3 o.d. by 0.3
Vapor cooler to condenser	4 o.d. by 0.120	10.2 o.d. by 0.3
Condenser to pump	1 Schedule 10 pipe	3.3 o.d. by 0.3
Pipes:		
Vacuum	2 o.d. by 0.065	5.1 o.d. by 0.2
Argon and nitrogen	$\frac{5}{8}$ o.d. by 0.095	1.6 o.d. by 0.2

bellows and an expansion loop were utilized in the NaK dump and fill lines to alleviate any flexure stresses.

Circular line heaters were placed on the expansion tank as well as on the dump and fill lines and lines from the loop to the expansion tank to avoid possibilities of oxide formation and plugging of these cooler portions of the loop.

Mercury loop. - The Hg loop operating on a Rankine cycle was the work loop of the system. Figure 1 shows the design parameters of the loop. The pump bypass line was incorporated to facilitate obtaining pump characteristics. A standpipe at the pump inlet was employed to control the liquid Hg inventory.

After the loop was constructed, to accommodate anticipated increases in flow rates for the loop, we decided to modify the turbine simulator bypass line so that it also could be utilized as part of the turbine simulator. A portion of the bypass line, denoted A to B in figure 1, was removed from the loop. The line, denoted A to C in figure 1, was added to the loop and completely eliminated the bypass line.

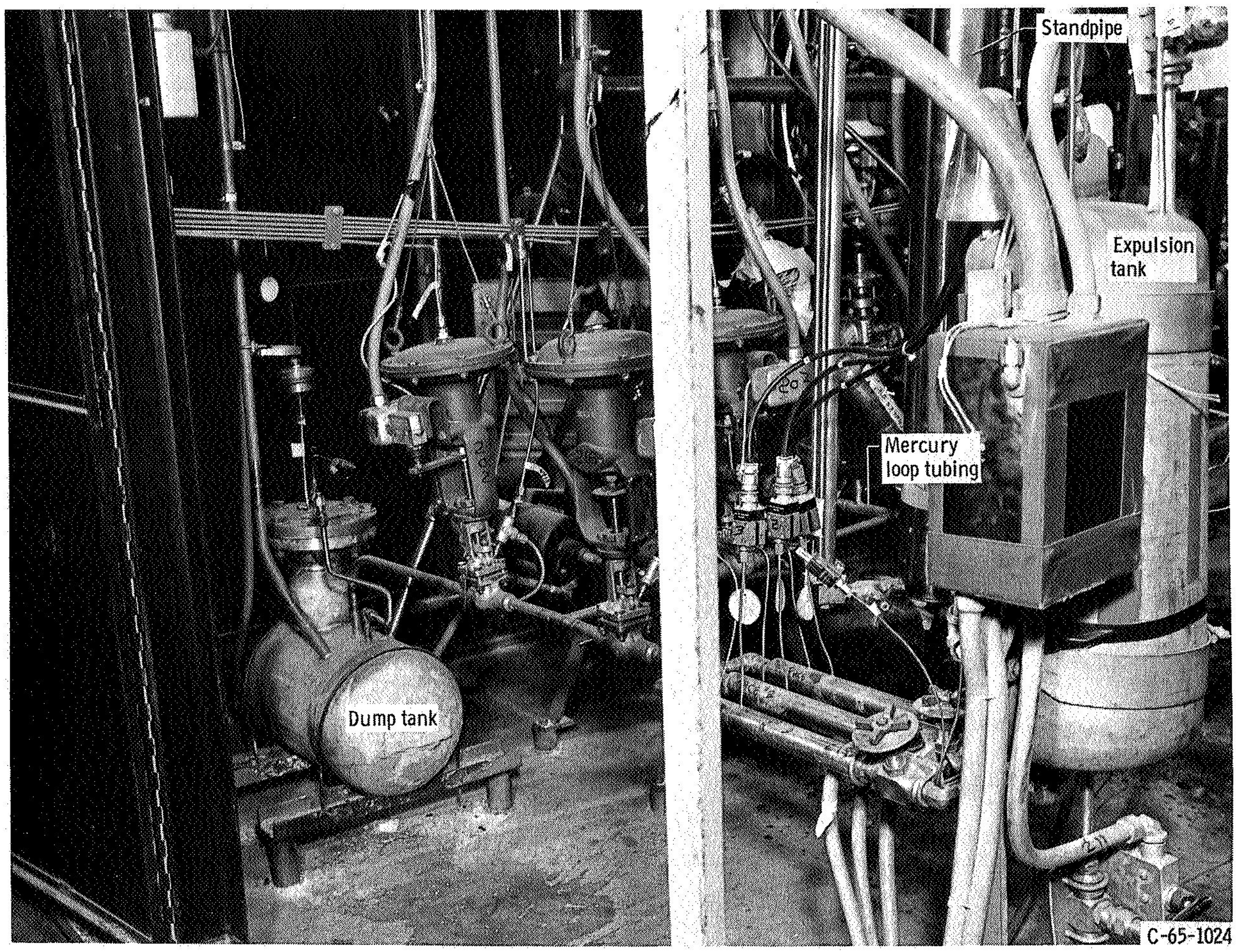


Figure 7. - Mercury fill and dump piping.

The Hg loop fill system consisted of an expulsion tank, three cavitating venturis with hand valves at the inlets, and two pneumatically operated on-off valves (see figs. 1 and 7). The expulsion tank was fabricated of 8-inch schedule-40 (20.3 cm, 0.8 cm wall) pipe with dished ends. The overall height of the tank was approximately 21 inches (53.2 cm). A funnel with a 16-mesh screen and a gaseous nitrogen pressurizing tube were welded to the top of the tank. The tank was suspended from a strain-gage load cell attached to the inner enclosure structure. The strain gage was used to obtain the weight of Hg in the loop. The venturis were located in parallel with one another so that flow rates for attemped simulated SNAP-8 startups could be varied. However, no simulated startup tests were conducted. To expel Hg from the tank to the loop, the tank was pressurized with nitrogen, and valves 216 and 203 (fig. 7) were opened to permit flow. Valve 202 (fig. 7) was closed so that Hg could not flow into the dump tank.

Draining of the loop was accomplished by opening valves 202 and 203 (fig. 7) located in the tubing connecting the loop to the dump tank. The valve nearest the dump tank (202

in fig. 7) served as a backup valve. Valve 216 (fig. 7) was closed after the loop was filled and prevented Hg flow into the expulsion tank.

The Hg dump tank was fabricated of AISI 316 stainless steel with an 8-inch (20.3 cm) length of 10-inch schedule-10 (25.4 cm, 0.4 cm wall) pipe and standard pipe caps. A drain line with a hand valve was welded at the bottom of the tank. A dump, a vent, cover gas lines, and a thermocouple well were located at the top of the tank.

The Hg pump was a $7\frac{1}{2}$-horsepower (5590-W) sealless canned motor type which was temperature limited to approximately 300° F (422° K). The pump bearings were cooled and lubricated by recirculating Hg. Factory-filling the stator cavities with a heat conductive dielectric oil cooled the motor. The heat of the motor then was able to flow quickly to the stator interior and from the rotor chamber to the outside of the motor. The coolant was pumped by a 1-horsepower (746-W) constant-speed centrifugal pump (located beyond the outer enclosure wall) through a heat exchanger enclosing the stator section of the Hg pump. The heat received by the coolant from the mercury pump was rejected to water in a heat exchanger located at the inlet to the coolant pump.

The starting load of the Hg pump was approximately 24 amperes at 440 volts and the running load was approximately 22 amperes. The rotational speed was 3450 rpm, and the stagnation pressure was in excess of 600 psia (414 N/cm^2 abs). To obtain pump-control-valve-combination characteristics, a control valve in the pump bypass line, in conjunction

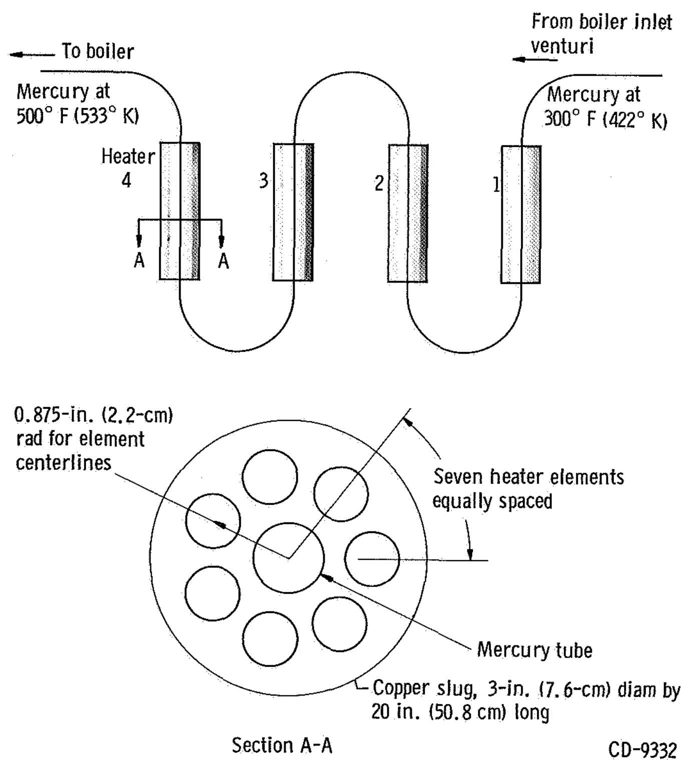


Figure 8. - Schematic drawing of mercury preheater.

with the pump outlet control valve, were adjusted to vary liquid flow rates and pressures downstream of the pump-control valve. Flow rates were calculated from measurements obtained from the pump inlet venturi.

The Hg line filter located downstream of the centrifugal pump-control-valve combination used a 20-micron sintered porous stainless-steel filtering element with a pressure drop of approximately 1 psid (0.7 N/cm^2 differential). A drain line with a hand valve and with a capped discharge line was welded to the bottom of the filter housing.

The boiler-inlet flow-control valve was a 1/2-inch (1.3-cm) valve which was originally hydraulically operated. Failure of O-rings in the hydraulic operator necessitated reverting to a pneumatic operator. This change restricted obtaining all the transient data originally desired.

The boiler-inlet venturi had an upstream and downstream inner diameter of 0.310 inch (0.8 cm). The throat was sized to allow flow rates of 9650 pounds per hour (1.22 kg/sec) with an upstream to throat pressure drop of approximately 20 psid (13.79 N/cm^2 differential). All the loop venturis were a standard ASME design.

The Hg preheater, shown schematically in figure 8, consisted of four slugs of copper encompassing the serpentine-shaped Hg tube. Each copper slug was drilled at close tolerances to receive seven tubular heating elements with a shrink fit. Since the Hg pump was temperature limited to 300° F (422° K), the preheater was employed to increase the temperature of the Hg to its design temperature level of 500° F (533° K) before it entered the boiler. Malfunction of some of the heating-element controls damaged some of the heating elements during the early stage of loop operation. As a result, the boiler-inlet temperature of 500° F (533° K) was no longer attainable.

The boiler outlet was welded to the inlet of the modified turbine simulator. The modified turbine simulator consisted of two valves and two venturis to simulate the pressure drop across a turbine and a Hg vapor cooler (Hg vapor to air heat exchanger) to simulate the temperature drop across a turbine (see figs. 9 and 10). The Hg vapor from the boiler flowed through right-angle hydraulically operated valves welded to each end of the boiler-outlet tee. Parallel lines, each with a choked venturi, were connected to the discharge ends of the right-angle valves. Each venturi was designed to choke at a flow rate of 8500 pounds per hour (1.07 kg/sec). The ratio of the flow rates determined by the vapor venturi measurement and the flow rate determined at the boiler-inlet venturi was used as an indication of the quality of the Hg vapor.

Flow through one of the two parallel lines passed through a second right-angle on-off valve before the two lines were joined at the inlet to the Hg vapor cooler (see fig. 10).

A burst disk located at the boiler discharge (fig. 1) was utilized to ensure against overpressurization of the vapor portion of the loop. The disk outlet was connected to the cell water scrubber system.

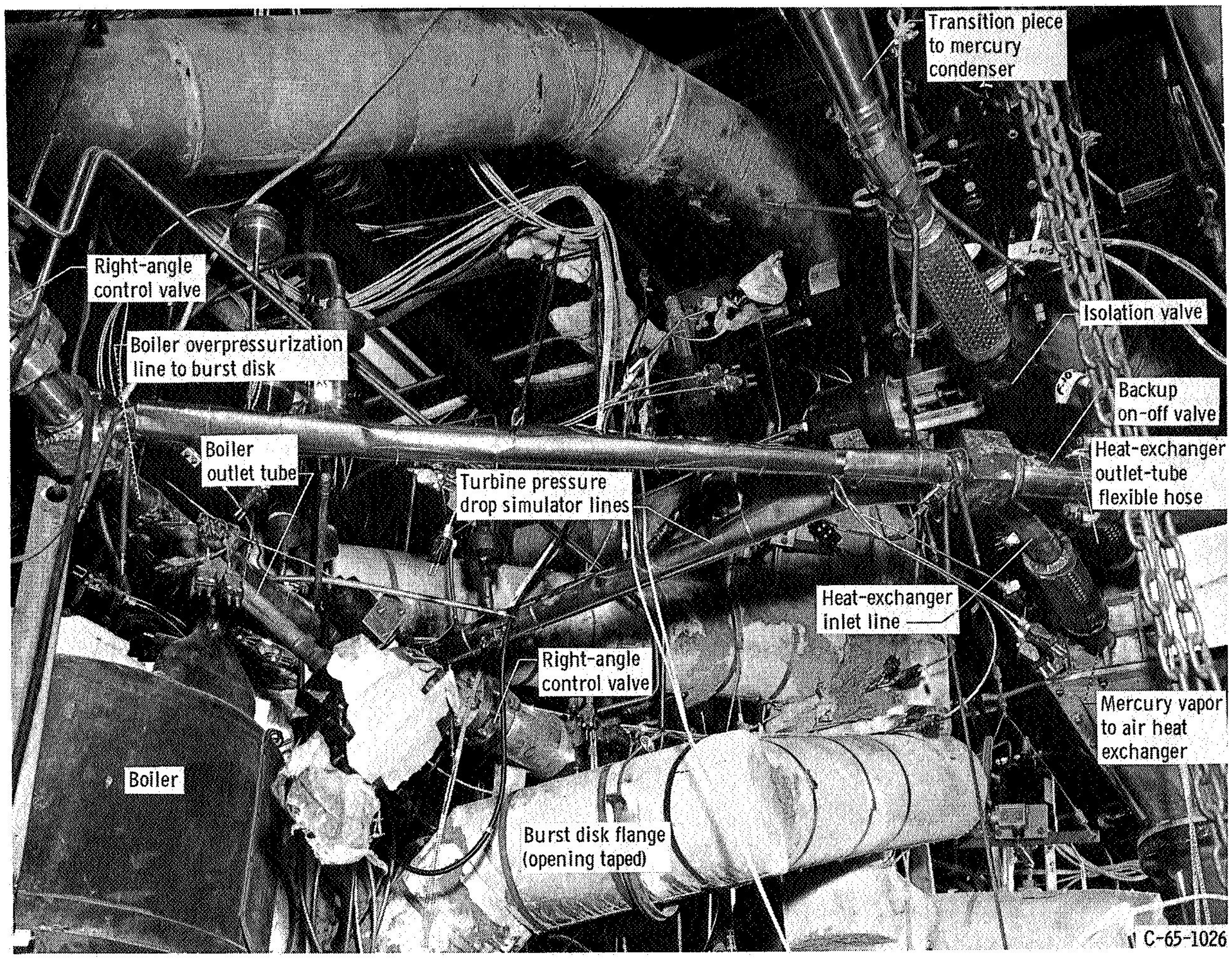


Figure 9. - Turbine pressure drop simulator lines.

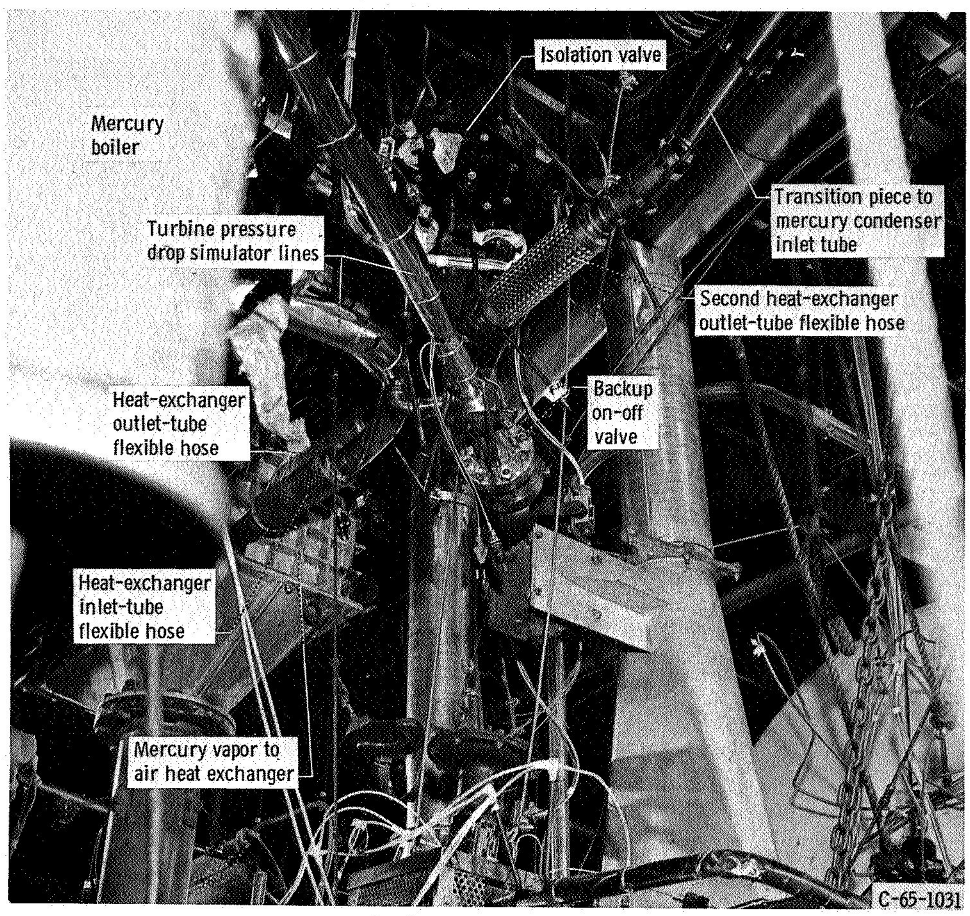


Figure 10. - Mercury vapor to air heat exchanger piping.

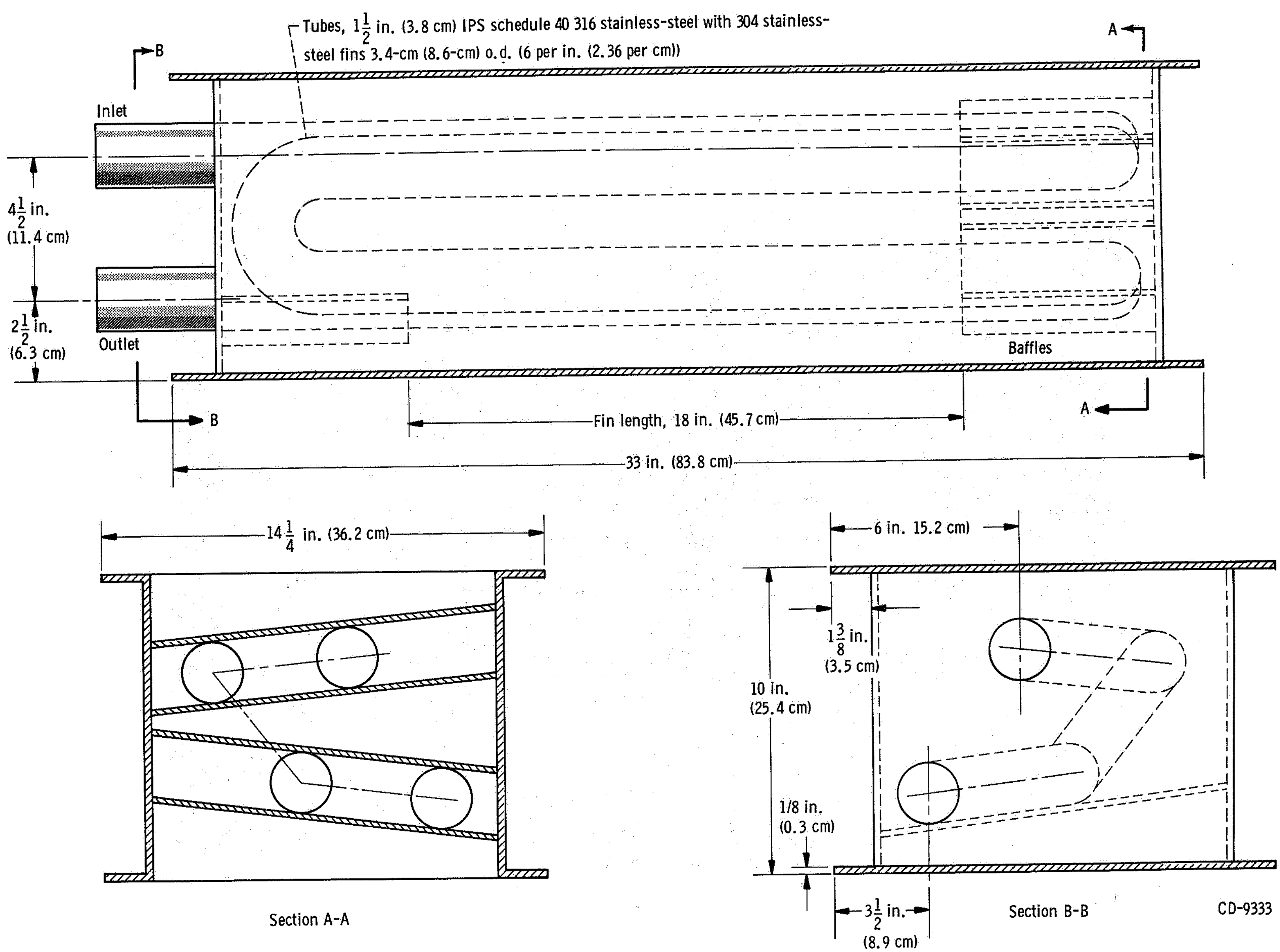


Figure 11. - Mercury to air heat exchanger.

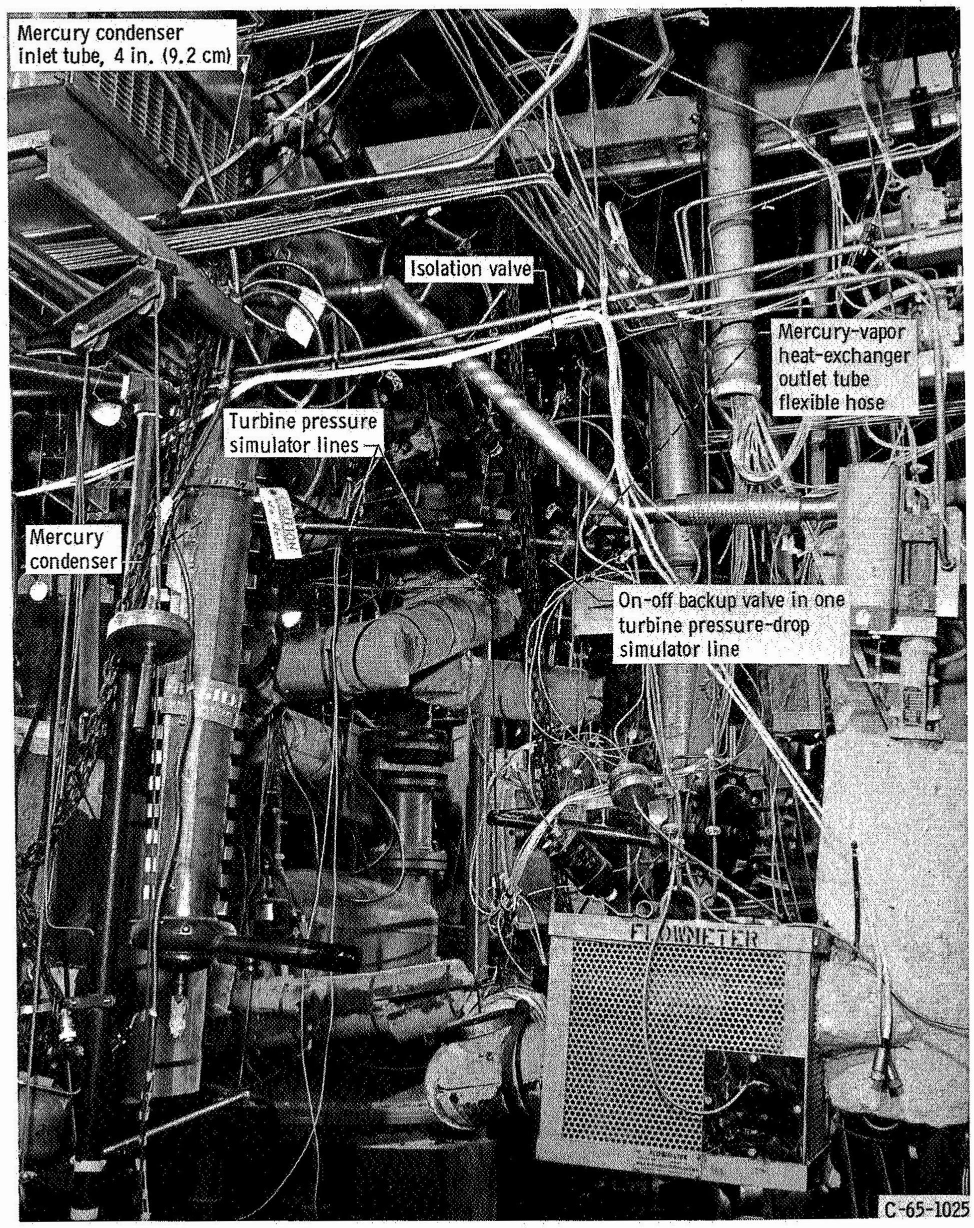


Figure 12. - Mercury condenser with condenser inlet piping.

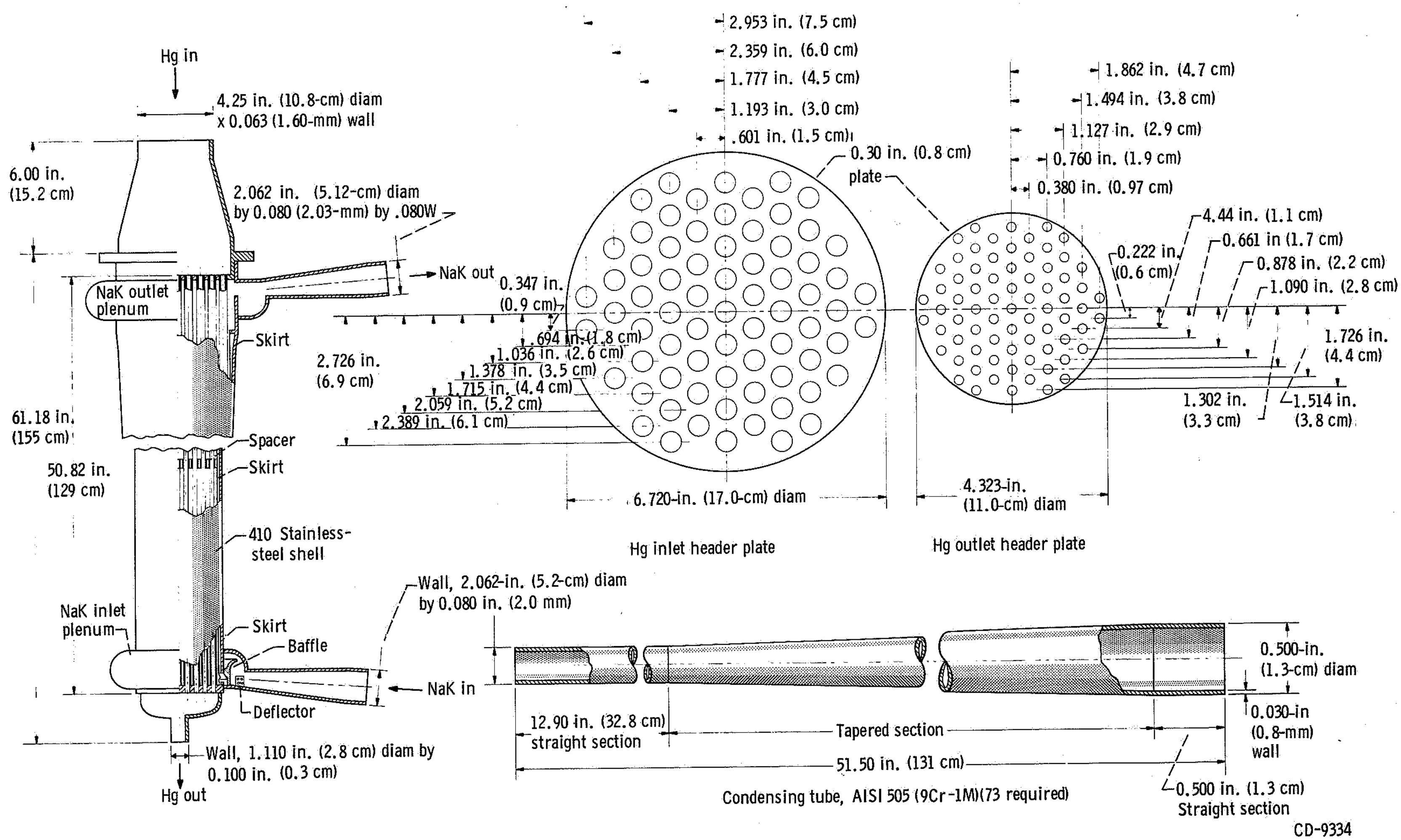


Figure 13. - Mercury condenser.

The Hg vapor to air heat exchanger (figs. 10 and 11) was the crossflow type, consisting of a four-pass partly finned pipe. The unit was designed to handle saturated Hg vapor flow rates of 7200 pounds per hour (0.91 kg/sec) at 1305° F (980° K) inlet temperature and a pressure drop of 2.5 psi (1.7 N/cm^2) with 7200 pounds per hour (0.91 kg/sec) of air coolant with an inlet temperature of 100° F (311° K). Mercury vapor outlet temperature was 700° F (644° K). Since the quantity of cooling air was not restricted and its inlet temperature was of the order of 70° F (294° K), the heat exchanger was capable of handling considerably larger Hg vapor flow rates than the loop design.

An on-off valve was employed at the outlet of the Hg vapor cooler to isolate the high-pressure from the low-pressure portion of the loop for implementation of pressure instrumentation calibration (see figs. 10 and 11).

The condenser (figs. 12 and 13) was designed and fabricated by the SNAP-8 system contractor. It is a counterflow single-pass heat exchanger which was freely suspended in a vertical position. Mercury vapor entered the condenser through a transition piece into a plenum chamber and through 73 tapered condensing tubes where liquefaction of the vapor and subcooling occurred. Heat was removed from the Hg by the NaK pumped from the heat-rejection loop through the condenser. The NaK entered the condenser passing through deflectors, around baffles, and through small holes drilled around the circumference of the extended tapered shell of the condenser into a toroidal plenum. The coolant flowed upward around each of the tapered tubes into an outlet torroidal plenum. The condensed Hg flowed into a liquid plenum at the bottom of the condenser.

The outlet of the condenser was connected to an on-off valve. The on-off valve was closed when the Hg pump-control-valve characteristics were obtained. The valve was sized so that it did not have an adverse effect on the net positive suction head of the pump.

Since the temperature of the Hg at the outlet of the condenser was 500° F (533° K) and the upper temperature limit of the Hg pump was approximately 300° F (422° K), it was necessary to subcool the Hg further to approximately 300° F (422° K) before the Hg entered the pump. Mercury subcooling was accomplished by a heat exchanger that utilized the coolant pumped from the same system used to accomplish Hg pump motor cooling. The heat exchanger (figs. 14 and 15) was designed to handle 12 000 pounds per hour (1.52 kg/sec) of Hg with a temperature drop of from 500° to 300° F (533° to 422° K). The large $1\frac{1}{2}$-inch (3.81-cm) outside diameter by 0.065-inch (1.65-mm) wall tubing was chosen so that the pressure drop would be minimal (calculated to be less than 0.1 psid (0.1 N/cm^2 differential)). Coolant flow to the heat exchanger, as well as to the Hg pump, was regulated by hand valves located at the coolant pump discharge.

The Hg pump-inlet venturi was located downstream of the Hg subcooler (see fig. 15). This venturi was used as a check on the boiler-inlet flow rate but its primary purpose was for use in obtaining characteristics of the Hg pump-control-valve combinations.

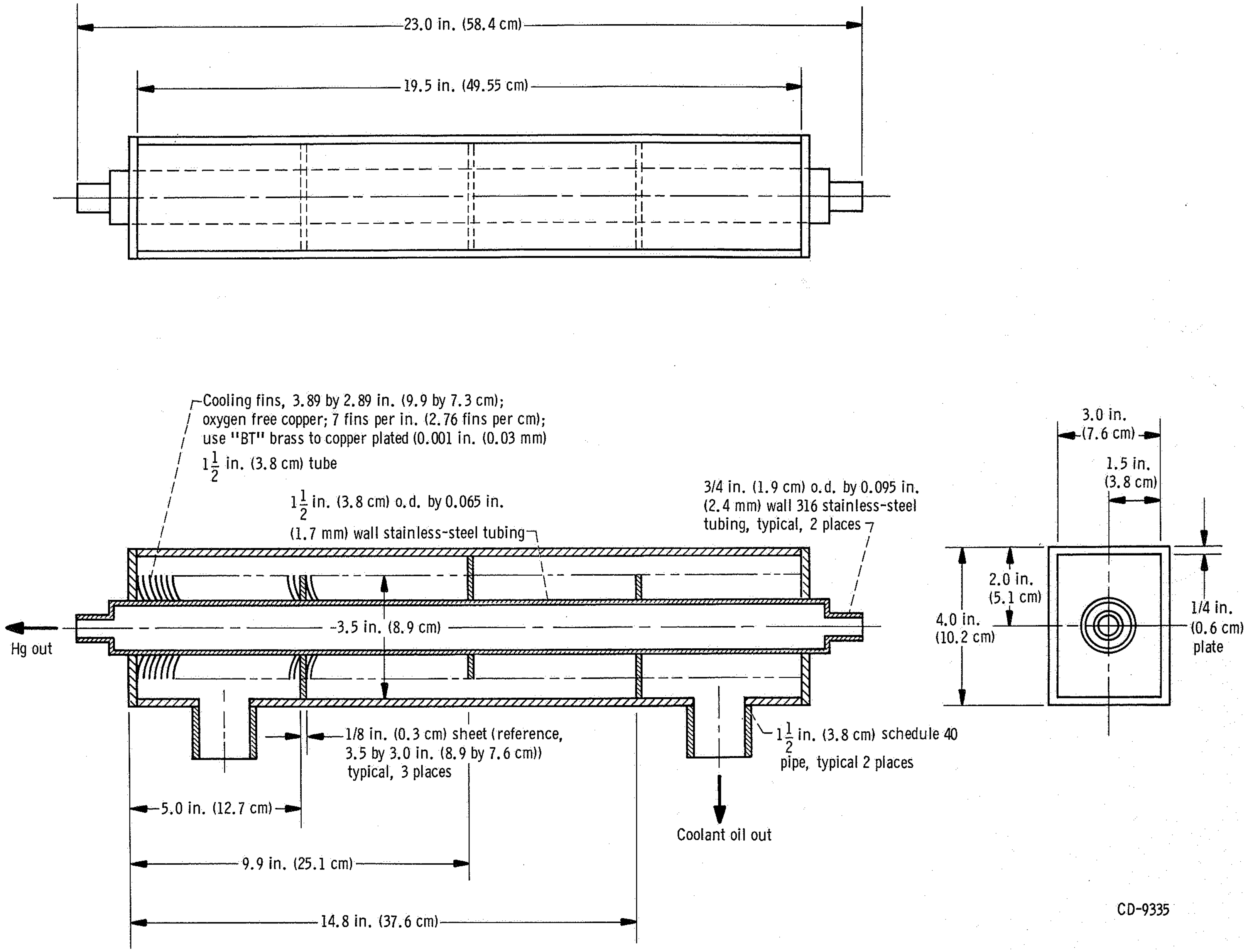


Figure 14. - Mercury to coolant oil heat exchanger.

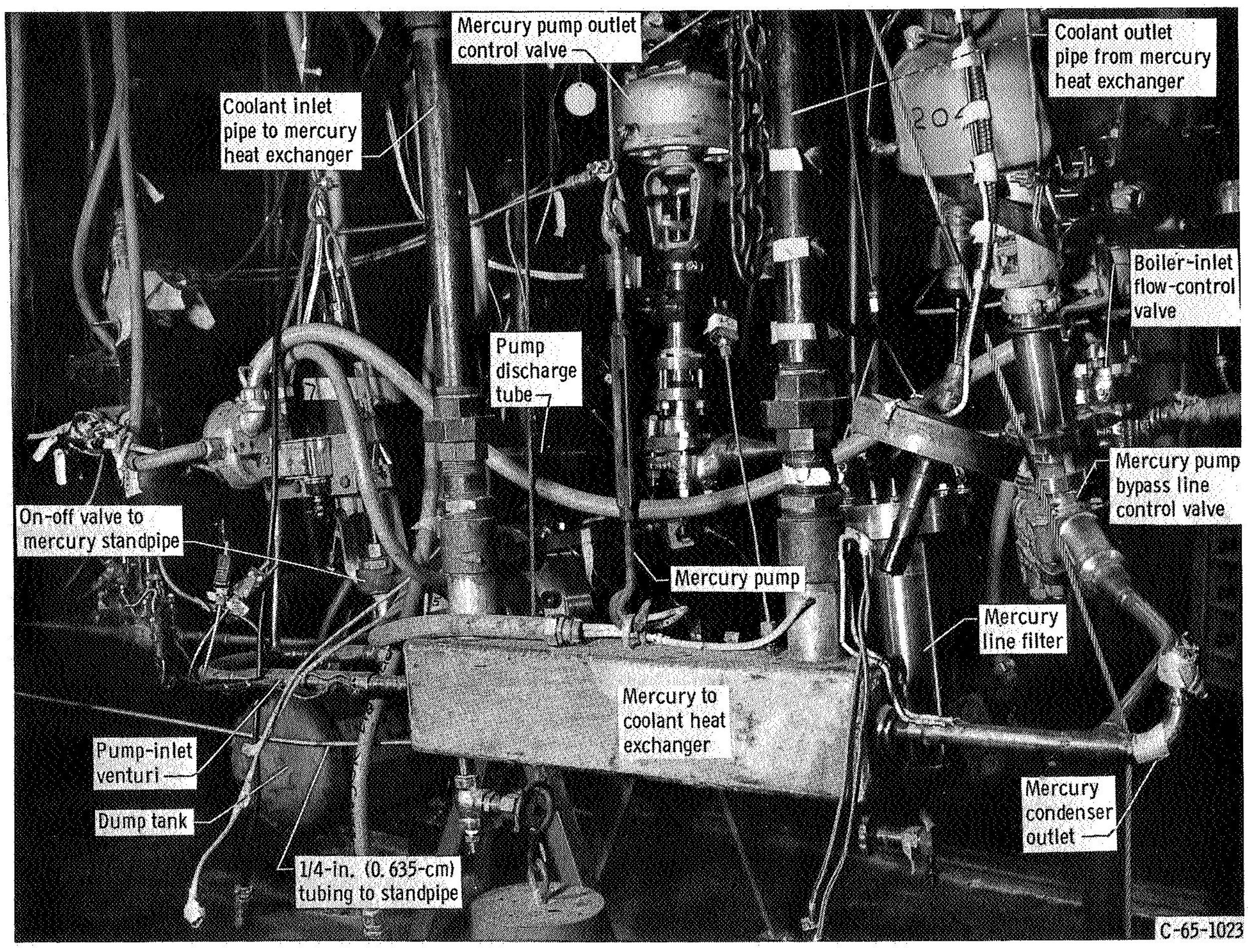


Figure 15. - Liquid portion of mercury loop.

The standpipe at the Hg pump inlet was a 3-foot (0.9-m) length of 4-inch (10.16-cm) outside-diameter by 0.032-inch (0.8-mm) wall tube (see fig. 15). The 1/4-inch (6.35-mm) tubing was sufficiently long and had a half loop formed near the on-off valve so that the weight of the standpipe was isolated from the main portion of the Hg loop. The standpipe was suspended from a strain-gage load-cell unit used to measure the weight of Hg in the standpipe before and during loop inventory changes.

A 1/4-inch (6.4-mm) outside diameter by 0.032-inch (0.8-mm) wall tube with a compound regulator connected the top of the standpipe to the nitrogen and the Hg loop vacuum systems. Inventory changes in the Hg loop were made by adjusting the pressure above the standpipe Hg level to either above or below the Hg pump-inlet pressure.

Circular line heaters were employed on the vapor portion of the loop and on the liquid venturi to reduce thermal losses.

Only three components, the dump tank, the Hg pump, and the Hg vapor cooler, were fixed in location. All other components were freely suspended or counterbalanced to provide minimum restriction to thermal growth. Flexible hoses, located at the Hg vapor-

cooler inlet and outlet, at the downstream side of the isolation valve, and at the condenser outlet, were employed to relieve flexure stresses due to thermal expansion.

Tubing and piping used in the liquid portion of the loop consisted of either AISI 316 or AISI 304 stainless steel. Type 316 was used exclusively in the high-temperature or vapor portion of the loop. (Line sizes are shown in table I.)

Heat-rejection loop. - The heat-rejection loop (fig. 1) consisted of an EM pump, the Hg condenser, two NaK to air heat exchangers, a condenser bypass line, three EM flowmeters, an expansion tank, valving, and a fill and dump line.

The EM pump was similar in mounting, size, and capacity to that utilized in the primary loop. The only difference between the two pumps was that due to the lower operating temperature of the heat-rejection-loop pump because its bus bars were fabricated with copper instead of nickel.

The total flow of the loop was determined by EM flowmeter 4 shown in figure 1. The flow into the Hg condenser was determined by EM flowmeter 5. Flow to the condenser was regulated by a three-way valve. Flow not entering the condenser passed through the third port of the three-way valve through the condenser bypass line. An on-off valve was positioned in the bypass line so that the three-way valve could also be employed as a throttle valve. The three-way valve was originally hydraulically operated so that the effects of flow perturbations on the condenser performance could be determined. However, during loop operation, failure of O-rings in the hydraulic operator required a change to a pneumatic operator on the valve.

The NaK from the condenser outlet was channeled through two NaK to air heat exchangers in parallel. These heat exchangers, in conjunction with the controlled air flow and analog computer, were used to simulate a space radiator (ref. 3). A control valve was employed at the inlet of each heat exchanger to divide the flow passing through each of the heat exchangers equally. An EM flowmeter was used to determine required control-valve positions.

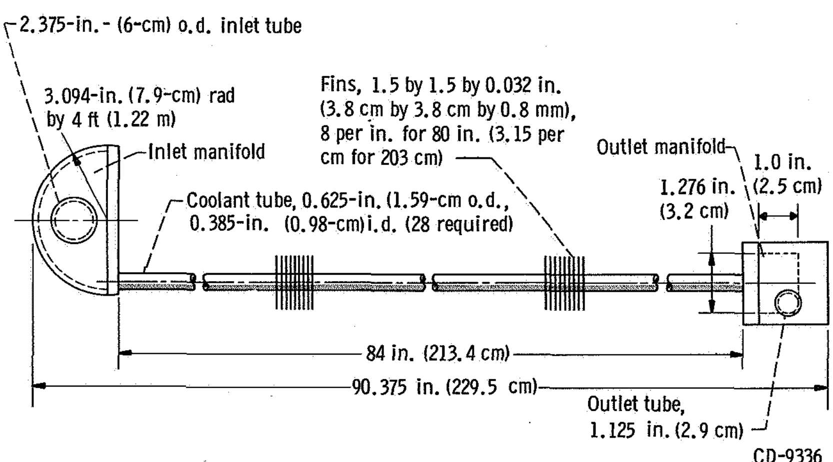


Figure 16. - Heat-rejection loop NaK to air heat exchanger.

A cross-sectional view of the heat exchanger is presented in figure 16. The heat exchanger consisted of a 4-foot- (1.22-m) long half-round inlet manifold and a 4-foot- (1.22-m) long rectangular shaped outlet manifold connected by twenty-eight 7-foot- (2.13-m) long finned parallel tubes. The heat exchangers were originally designed to simulate the mass and heat transfer required of a SNAP-8 system space radiator when the system was a two-loop system employing a direct condensing radiator. With the addition of the heat-rejection loop to the system, it was decided to utilize these units as NaK to air heat exchangers. The heat exchangers were positioned in a 5-foot- (1.52-m) diameter by 10-foot- (3.05-m) long tank which served as the coolant air housings. The heat exchangers were supported at the two ends of both manifolds from the interior walls of the tanks by cables.

A tube with a pneumatically operated on-off valve connected the loop at the EM pump inlet to an expansion tank similar to the one utilized in the primary NaK loop. Another line connected the high point of the loop at the condenser outlet to the expansion tank. This line, with a pneumatically operated on-off valve was used to remove entrapped gases in the loop during filling operations. A fill and dump line with a pneumatically operated on-off valve was welded to the loop downstream of the pump. (Tubing sizes used in the loop are shown in table I.)

The pump and a portion of each inlet and outlet line of the NaK to air heat exchanger (points of penetration of these lines through the coolant air housings) were fixed in location. All other components were freely suspended by cables. Flexible hoses at the inlet and outlet of the condenser and upstream and downstream of the points of penetration of the heat-exchanger lines were installed to provide for safe thermal expansion of the loop piping.

Circular line heaters were installed on the loop piping and dump and fill line to prevent possible plugging. These heaters were also employed to bring the loop to the temperature level required for hot flushing the loop and to preheat the condenser and NaK to air heat exchanger prior to system operation.

NaK purification loop. - The NaK purification loop (NPL) was positioned physically to be as close to the primary NaK loop and to the heat-rejection loop as possible. NaK from either the primary or heat-rejection loop was piped to the NPL loop by two transfer lines which interconnected the primary and heat-rejection loop, shown schematically in figures 1 and 17. A schematic drawing of the NPL loop piping is presented in figure 18. Line heaters were located on all the tubing, the valves, the plugging valve cooler, and on the cold trap, as well as on the two transfer lines. An on-off valve connected the bottom of the primary loop expansion tank to the high point in the NPL loop at the inlet to the EM flowmeter (fig. 18). This line was utilized to remove entrapped gases in the loop during the fill process. The on-off valve was in the closed position during loop operation.

Temperature of the NPL loop was maintained at slightly lower temperatures than the NaK in the loop to be sampled. The economizer (tube-in-tube heat exchanger) was in-

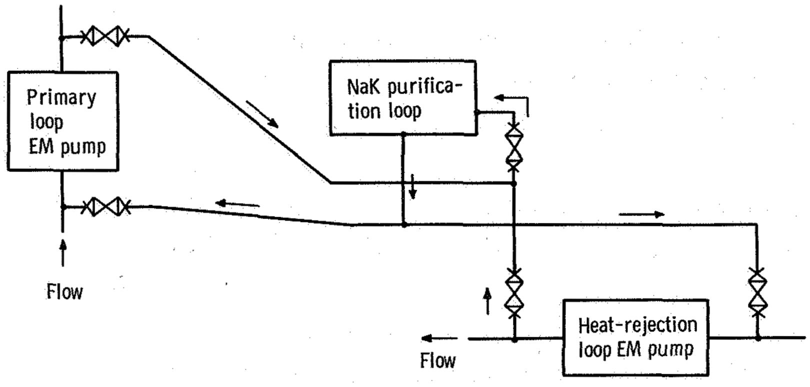


Figure 17. - Schematic drawing of interconnection of NaK purification loop with primary and heat-rejection loops.

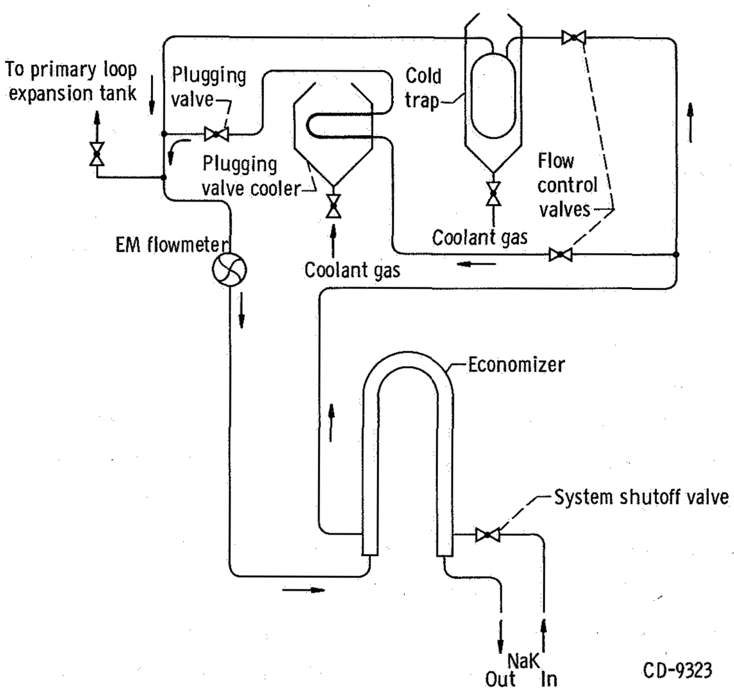


Figure 18. - Schematic drawing of NaK purification loop.

stalled to prevent excessive heat losses. The EM pump in the loop being cleaned pumped the NaK through the NPL loop (fig. 17).

NaK oxide content of the loop being sampled was determined by passing the NaK through the plugging indicator valve. The plugging indicator valve had slots machined in the seat that allowed a small amount of flow through the valve when it was closed. The flow-control valve upstream of the plugging valve cooler maintained flow through the plugging indicator valve of 1 gallon per minute (3.79×10^{-3} m^3/min).

As NaK flowed through the plugging valve, the temperature was slowly reduced by using the cooler until NaK oxides precipitated, plugging the slots in the valve. The oxide

content could then be determined from charts knowing the temperature at which precipitation occurred. After the plugging temperature was determined, both valves were opened and cooling stopped. The hot NaK and large flow dissolved the oxides plugging the machined slots.

Oxides were removed from the NaK by precipitation in the cold trap. NaK flow into the cold trap was set at 1 gallon per minute (3.79×10^{-3} m^3/min) by the flow-control valve upstream of the trap. At this flow rate, it took approximately 10 minutes for a NaK particle to go through the cold trap. The temperature of the cold trap was kept at approximately 50° F (27.8° K) below the indicated plugging temperature of the NaK. Cleaning the NaK was continued until an oxide content of approximately 20 parts per million was reached.

Vacuum System

Vacuum for the NaK loops was obtained with a 2-horsepower (1491-W) 46-cubic foot-per-minute (21 700 cm^3/sec) compound-staged pump. A 2-inch (5.1-cm) outside-diameter by 0.065-inch (1.7-mm) stainless-steel tube line connected the pump to the NaK loops at the NaK to air heat exchanger inlet tee of the heat-rejection loop and at the dump tank. Two liquid metal seated valves were located near the dump tank and at the inlet to the NaK to air heat-exchanger tee. The second valve served as a backup. A soft-seated valve and a solenoid valve were employed closer to the pump. A 5/8-inch (1.6-cm) outside-diameter by 0.095-inch (2.4-mm) wall tube line was teed into the 2-inch (5.1-cm) line and connected the expansion tanks of the primary and heat-rejection loops to the vacuum loop. A compound regulator was located in this line to control expansion tank pressure. Cold traps were used between the vacuum pumps and the liquid metal loops. The traps, located in a large insulated container, were cooled to approximately -60° F (222° K) by automatically controlling the level of liquid nitrogen in the large container. Vacuum measured at the pump was approximately 15 to 20 torr (2000 to 2670 N/m^2).

Vacuum in the Hg loop was obtained with a 2-horsepower (1491-W)47-cubic-foot-per-minute (22 200 cm^3/min) single-staged pump. A 2-inch (5.1-cm) outside-diameter by 0.065-inch (1.7-mm) wall stainless-steel tube was employed to connect the pump to the Hg loop at the dump tank and at the condenser inlet. Two metal seated valves were utilized in the lines close to the liquid metal loop. A soft seated valve and a solenoid valve were employed near the vacuum pump. The 2-inch (5.1-cm) line was connected to a cold trap located in the large insulated container before it was welded to the liquid metal loop.

Argon Gas System

Argon gas was utilized as the cover gas for the liquid metal loop dump tanks and expansion tanks as well as for inerting the system when the system was not operating. Argon from a large 3000 psig (2070 N/cm^2 gage) supply tank, located outside the building, was piped to two gas panels where the pressure was reduced by regulators to the required pressure (approx 50 psia (34.5 N/cm^2 abs)). Pressures to the liquid metal loops were regulated by remote controllers located in the control room. Argon from the gas panels flowed through cold traps located in the large container before they were connected to the liquid metal loops.

Connections to the loops were made at the primary and heat-rejection-loop expansion tanks by the compound regulator employed in the NaK vacuum loop, at the NaK dump tank, the Hg dump tank, and the Hg vapor cooler outlet. Two metal seated valves in series were utilized at the NaK and Hg dump tanks as well as at the connection made at the Hg vapor cooler outlet. Soft seated valves were employed on the lines to the expansion tanks. These valves, as well as the compound regulator, were located on the gas panel.

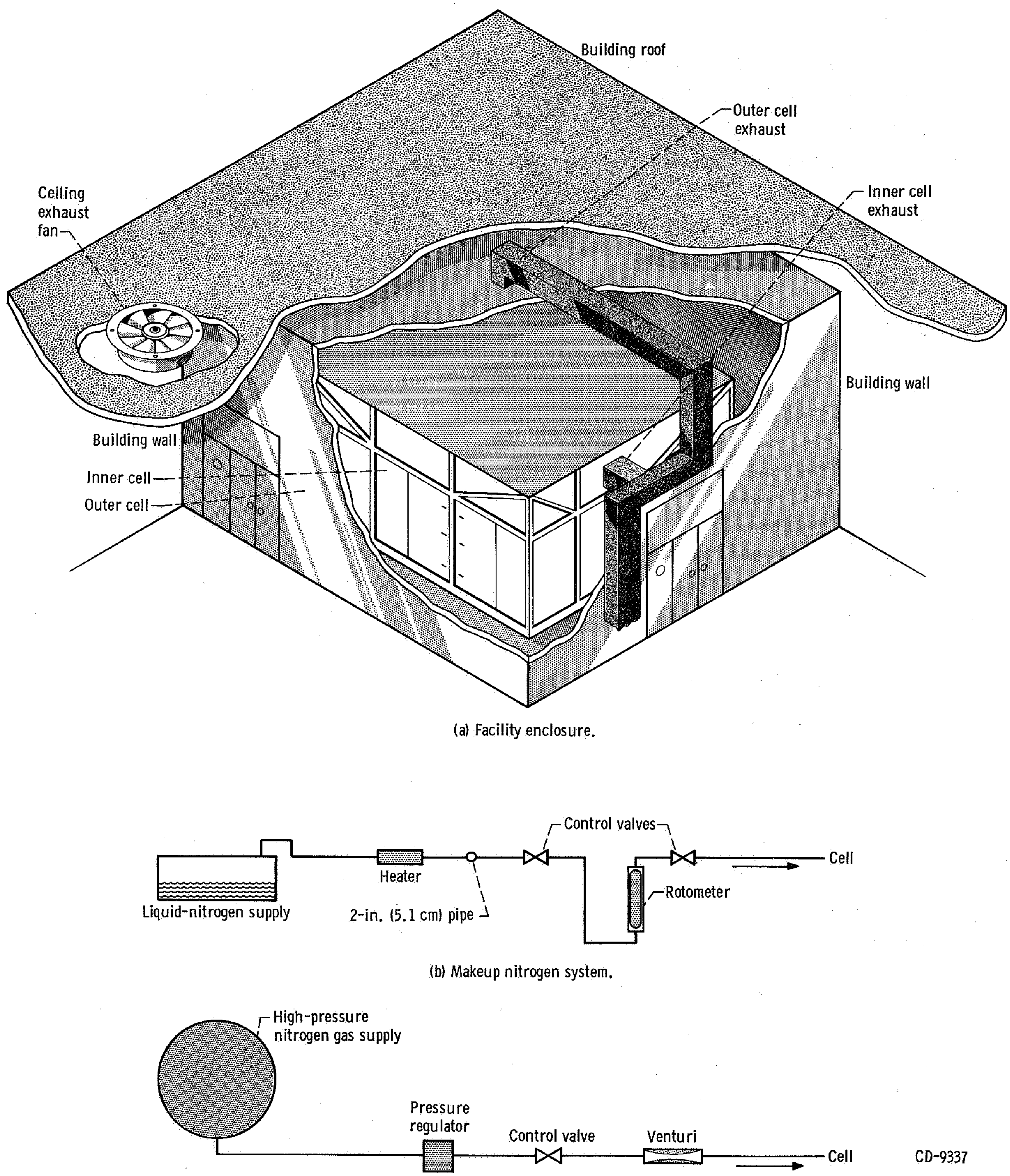
A pressure vent line was provided for both the Hg and NaK dump tanks. Both systems consisted of metal seated valves at the dump tanks and cold traps in the lines. Soft seated solenoid valves with 35-psia (24.1 N/cm^2 abs) relief valves in parallel were on the cold-trap outlets. The NaK dump tank vent was exhausted into the cell while the Hg dump tank vent exhausted into the facility water scrubber. The two expansion tanks were vented through the compound regulator to the vacuum system.

Nitrogen Gas System

Nitrogen (N_2) was employed to pressurize the Hg expulsion system as well as to actuate the pneumatically operated valves of the system. Gaseous N_2 obtained from a 7-foot- (2.13-m) diameter sphere was piped to the gas panels where the pressure was reduced as required. The pressure of the N_2 to the Hg expulsion tank was regulated by a controller located in the control room.

A separate gaseous N_2 system was employed to inert the facility during system operation. Because of the hazards of the liquid metals, the location of the test facility and the preliminary results obtained from reference 4, it was decided to inert the facility with gaseous N_2 during loop operation.

All holes and openings in the concrete floor were sealed to prevent liquid metal spills from getting into the basement of the building. To seal the outside cell, all joints were sprayed from the inside with polyurethane rigid foam (see fig. 19(a)). The oxygen content in the inner cell was maintained at 2 to 5 percent, while the outer cell was maintained



(a) Facility enclosure.

(b) Makeup nitrogen system.

(c) Initial inerting nitrogen system.

Figure 19. - Schematic drawing of gaseous nitrogen inerting system.

at 3 to 5 percent. The N_2 that did leak through the outer cell wall was exhausted from the building through a ceiling fan. Nominal leakage through the outer cell was 2000 standard cubic feet per hour (56.64 m^3/hr) with a slight positive pressure of about 0.01 inch (0.3 mm) of water inside.

N_2 gas was supplied from two courses: (figs. 19(b) and (c)) a high-pressure gas sphere and a liquid Dewar. Approximately 4 hours were required to reduce the oxygen of the inner enclosure to the 3-percent level. Once this level was obtained, the makeup N_2 was supplied from the liquid boiloff of the N_2 Dewar. The liquid boiloff provided up to 5000 standard cubic feet per hour (141.6 m^3/hr) of gaseous N_2.

The cell was vented to atmospheric conditions by drawing air in through the outer doors and pulling the N_2 out through exhaust ducts in the outer and inner cells. The ducts were connected through the facility water scrubber to a blower on the roof of the building. Approximately 1/2 hour was required to vent the inner and outer cell to safe atmospheric conditions.

Air Cooling System

The air required to cool the EM pumps and the NaK and Hg heat exchangers was supplied at 40 psig (27.6 N/cm^2 gage) at approximately 70° F (294° K) to the cell enclosure, by a 48-inch (122-cm) line in the basement of the building. The air outlet piping from the cell enclosure is shown schematically in figure 20. Orifice plates were installed in lines to the heat exchangers. Electropneumatic butterfly valves were used in the NaK heat-exchanger lines to obtain transients for the planned radiator simulation tests.

The exhaust lines of the two NaK heat exchangers and of the two EM pump housings were manifolded and returned to the spray cooler. Any NaK vapors in the lines due to a leak in the NaK plumbing would be scrubbed by the water in the spray cooler before being exhausted to the atmosphere. The exhaust air from the Hg heat exchanger was passed through the facility water scrubber adjacent to the cell enclosure (fig. 2(b)) before it was exhausted to the atmosphere. Samples of the exhaust were taken by a vapor leak detector.

Hydraulic System

A hydraulic system was required to operate the heat-rejection-loop condenser bypass control valve, the boiler-inlet Hg flow control valve, and the two right-angle control valves at the Hg discharge of the boiler. Hydraulic operation was deemed necessary for the dynamic studies planned. The hydraulic fluid selected was a phosphate ester which would not support combustion in the event of a NaK fire.

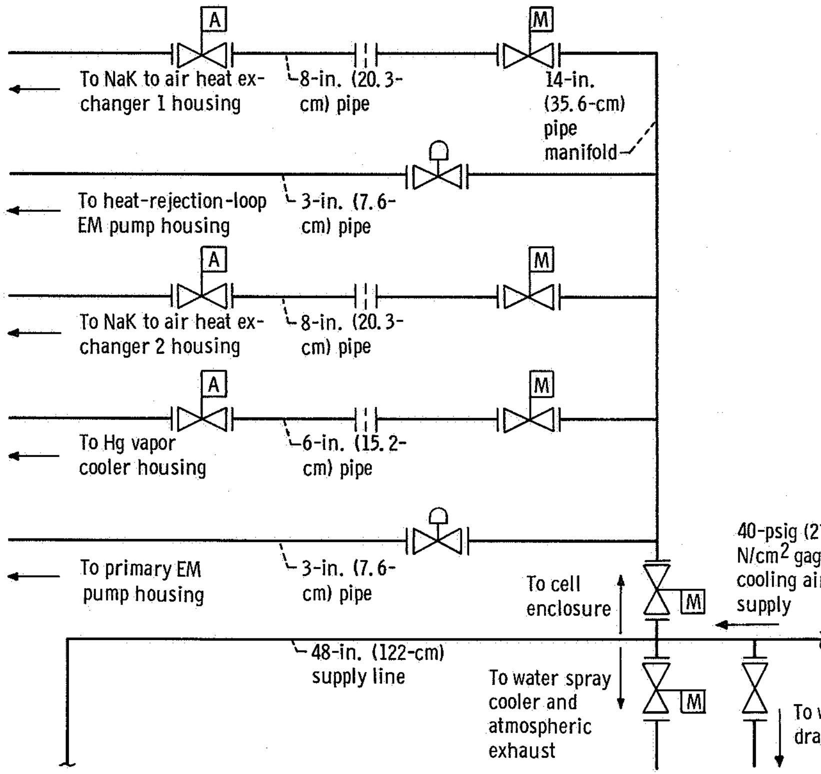


Figure 20. - Schematic drawing of facility cooling air system.

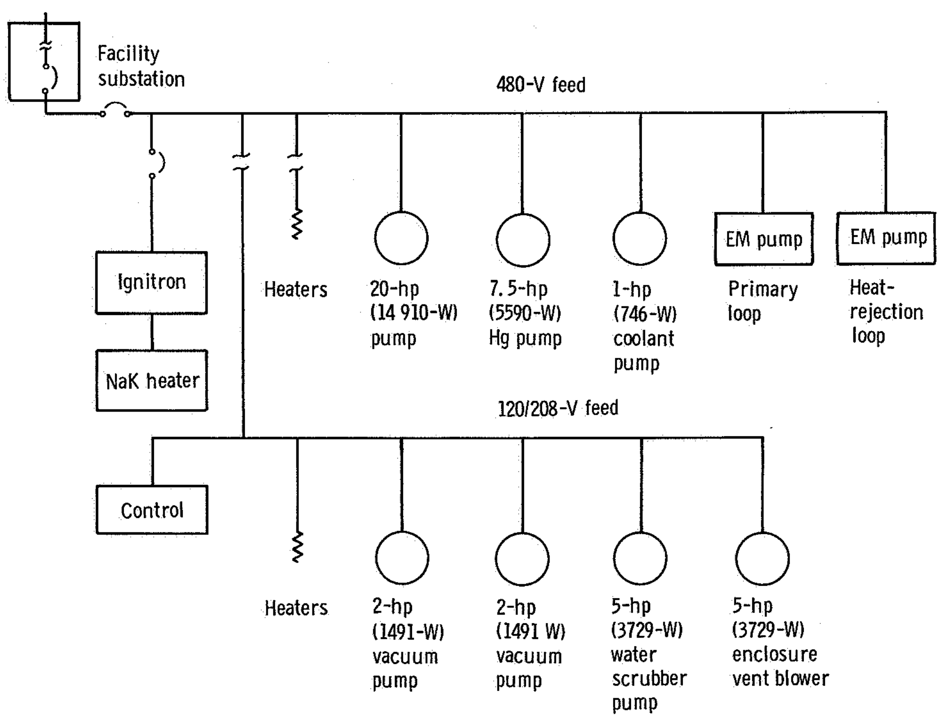


Figure 21. - Schematic drawing of electrical power system.

Electrical System

A schematic drawing of the electrical power system is presented in figure 21. The electrical system of the SNAP-8 simulator loop was fed from a substation in the basement of the building. Three-phase 480-volt power was fed by a 1000-ampere breaker to the test cell and the ignitron controller located in the basement. The ignitron controller had its own 600-ampere circuit breaker remotely operated from the control room.

The 480-volt power fed the hydraulic, Hg, and cooling oil pumps. Single-phase 480-volt power was used for the two EM pumps. Heavy heating loads for the loops were fed from the 480-volt source by a 90-kilowatt transformer.

The 120/208-volt power required for the test cell was derived by a 112.5-kilovolt-ampere transformer fed from the 480-volt power. Two vacuum pumps, a 5-horsepower (3729-W) scrubber water-circulating pump, a 5-horsepower (3729-W) cell ventilating blower, and the line heaters were fed from this source. The remaining load consisted of control power for the control room.

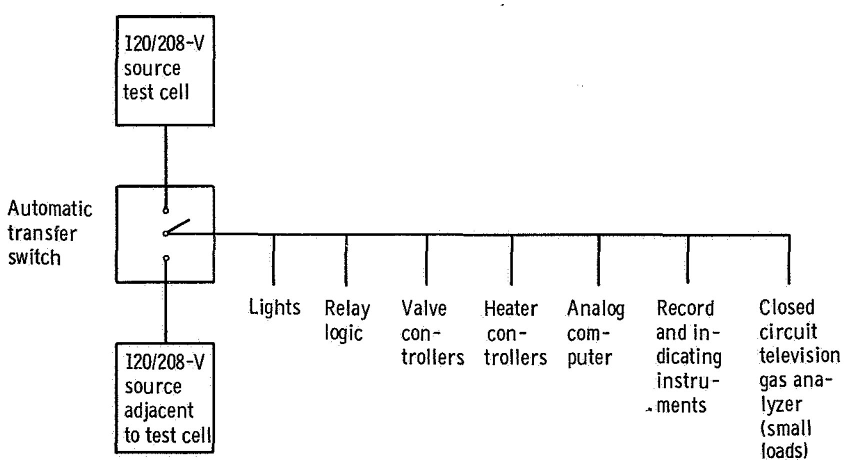


Figure 22. - Schematic drawing of control power arrangement.

Continuity of control power was assured by employment of a 100-ampere automatic transfer switch providing an alternate source of control power from an adjacent test cell. In the event of loss of power from the facility substation, this arrangement permitted an orderly shutdown of the system. Remaining control power loads are shown in figure 22.

The power level of the NaK heater which served as the heat source in the primary loop, was controlled by an ignitron controller powered from the 480-volt power lines, as shown in figure 23. Control from zero power level to maximum were attained by either (1) open loop manual power setting, or (2) closed loop set point power level, or (3) analog computer control by a 0- to 65-millivolt signal. A separately adjustable load-limit stop established maximum attainable load voltage during any mode of operation.

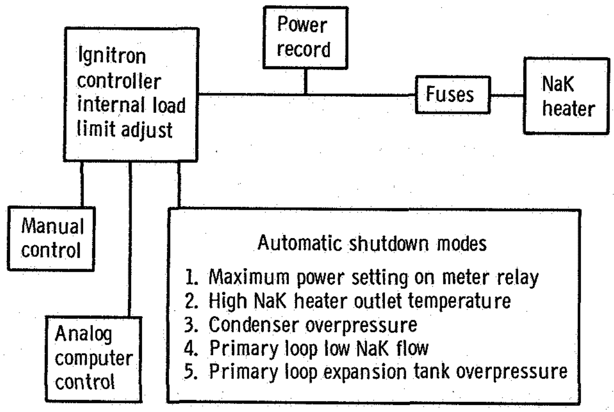


Figure 23. - Schematic drawing of NaK heater wiring.

The NaK heater elements were wired as follows: every pair of elements was connected in series, and all series pairs were connected equally in parallel for each of 3 phases. Individual heating-element line fuses were employed with the backup heater at the heater location to limit fault currents in the event of heating-element grounding to the frame or short circuit in the element. One fuse was provided for each of two heating elements connected across the controlled 480-volt phase potential. Automatic shutdown of power to the heater was employed as a safety measure on the sensing of abnormal operation of the system. The conditions which would cause shutdown are hereinafter described:

(1) Attainment of maximum power level corresponding to the set point on a control-room-panel meter relay: the set point of this controller was adjusted for an upper limit considered safe for the mode of operation.

(2) High temperature at NaK heater outlet: this temperature was read out on the control-room-panel meter relay with an adjustable set point set for a safe operating condition.

(3) Condenser over pressure: this condition was sensed at the condenser inlet by a pressure transducer and read out on a control-room-panel meter relay. A high set-point set of contacts on this meter effected a shutdown.

(4) Primary loop low NaK flow: NaK flow was indicated by a control-room-panel meter relay actuated from signal received from an EM flowmeter in the primary loop. When the indicated flow approached the low setpoint of the instrument, power shutdown resulted.

(5) Primary loop expansion tank overpressurization: This was monitored by a pressure switch connected to the argon cover gas line for the primary loop expansion tank.

The EM pumps were protected against overheating by loss of flow by using a meter relay indicating NaK flow. Additional protection was provided to the EM pumps by returning the pump controls to off each time a shutdown occurred. Figure 24 shows how this was done by using the normally closed contact on the positioning motor.

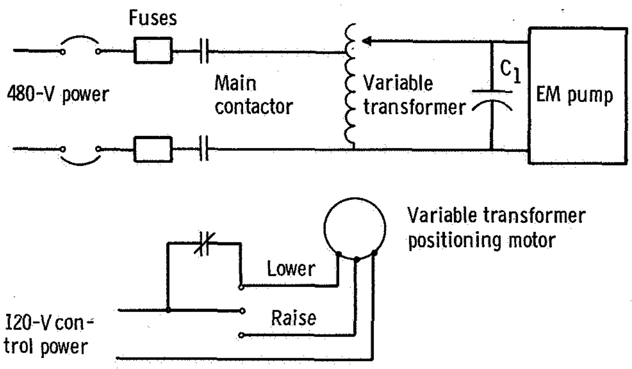


Figure 24. - Schematic drawing of electromagnetic pump control.

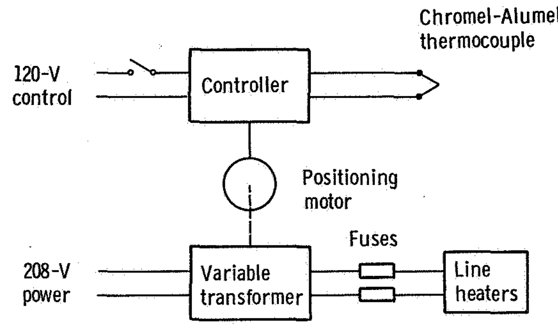


Figure 25. - Schematic drawing of line heater control.

Electric line heaters were installed on the piping, venturis, and selected transducers to ensure against oxide plugging and to offset heat loss through the insulation. The heaters consisted either of commercially available circular elements clamped against the process piping or insulated alloy resistance wire for irregular shaped components. Heaters were controlled thermostatically to achieve the desired pipe wall temperatures. A capacity of 70 kilowatts was provided. Heat input was controlled, as shown in figure 25. Each heater circuit was fused on the heater side to minimize the chance for a burnthrough of the process piping in the event of a heater fault.

Facility Test Support Equipment

Valves. - The valves controlling the process fluids in the SNAP-8 simulator loop were basically three types, and the typical controls are shown in figure 26.

(1) Hand-operated valves: the position of these valves operated a limit switch which operated indicating lights on the control panel.

(2) Pneumatic controlled valves: these valves were electrical solenoid actuated from the gaseous nitrogen system.

(3) Electrohydraulic valves: control of these valves was effected through the use of a controller servoamplifier electrically coupled to a servovalve in a closed-loop positioning system. Actuating power for the valve was obtained from the high-pressure hydraulic system.

All liquid metal valves were of the metal to metal seat type with either the plug, the seat, or both stellited and with bellows seals on the stems. The valves were either pneumatically or hydraulically operated. Linear potentiometers were utilized to indicate plug position for the heat-rejection-loop condenser bypass control valve, the heat-rejection-loop NaK to air heat-exchanger inlet-flow control valves, the Hg boiler-inlet flow-control valve, the Hg pump-outlet control valve, and the Hg pump bypass line control valve. All valves, manually, electrically, electropneumatically, or pneumatically operated had limit

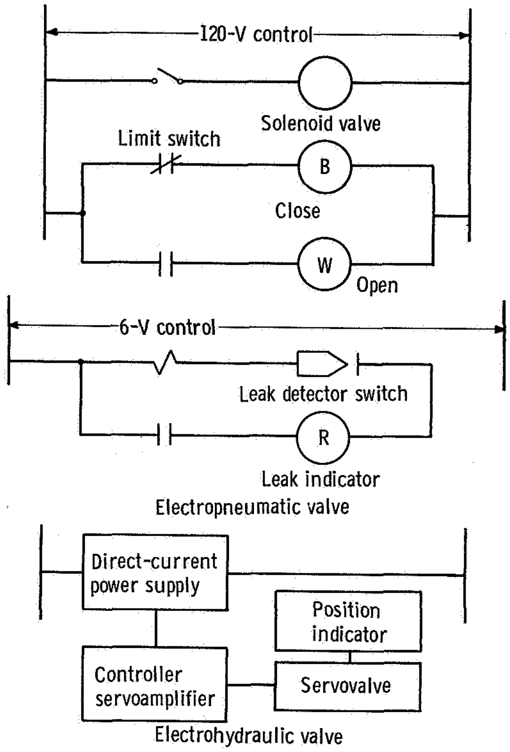


Figure 26. - Schematic drawing of valve controls.

switches at the end of their travel. Contact with the limit switches illuminated lights on the control panel to indicate plug position.

Facility water scrubber. - This scrubber was located in the cell adjoining the outer enclosure wall of the facility (fig. 2(b)). The scrubber contained a bed of ceramic baffles through which air passes. Water flows over the baffles to provide a washing action. The scrubber was utilized to prevent the NaK or Hg vapors from entering the atmosphere.

Flexible hoses. - Since dynamics were a prime consideration of the test, flexible hoses instead of tubing expansion loops were employed. Single-ply seam-welded AISI 316 stainless-steel flexible hoses were employed to accommodate thermal expansion of the liquid metal plumbing by lateral movement at the bellows rather than by contraction or expansion of the bellows. A 316 stainless braid was incorporated in the flexible hose construction to prevent bellows elongation. The location and pertinent flexible hose dimensions are presented in table II.

Loop insulation. - All tubing and all components of the NaK oxide control loop, the primary and heat-rejection loops as well as the Hg loop tubing and components, where Hg vapor was present (boiler to vapor heat exchanger to condenser), were covered with rigid high-temperature thermal insulation. The tubing of the liquid portion of the Hg loop was not insulated. All flexible hoses in the insulated portions of the loops were covered by a blanket high-temperature thermal insulation which did not interfere with the desired lateral motion required of the flexible hoses.

TABLE II. - FLEXIBLE HOSES EMPLOYED IN LIQUID METAL LOOPS

Location	Lateral movement		Maximum pressure		Maximum temperature		Bellows wall thickness	
	in.	cm	psia	N/cm^2 abs	^oF	^oK	in.	mm
Hg outlet of Hg condenser	±1	±2.5	60	41.4	700	644	0.016	0.4
Heat-rejection-loop NaK inlets to air heat exchangers	±1/2	±1.3	300	207	700	644	.020	.5
Primary NaK loop EM pump inlet and outlet; NaK dump tank inlets	±1	±2.5	60	41.4	1100	866	.024	.6
Heat-rejection-loop Hg condenser bypass line; heat-rejection-loop Hg condenser inlet and outlet	±1	±2.5	60	41.4	700	644	.022	.6
Hg vapor cooler inlet and outlet Hg vapor inlet to Hg condenser	±1	±2.5	300	207	1300	977	.024	.6
Heat-rejection-loop NaK outlets from air heat exchangers	±1/2	±1.3	60	41.4	700	644	.024	.6

Facility Instrumentation

Flowmeters. - Five permanent magnet flowmeters were used. A calibration was obtained on the smallest EM flowmeter used, that in the NaK purification loop. Facilities to calibrate the larger flowmeters were not available. However, a venturi was installed in the heat-rejection loop so that a check on the loop total flow flowmeter could be made. Agreement of total loop flow rate obtained between the two methods was within ±5 percent.

Mercury liquid and vapor flow rates were determined by the use of venturis. These venturis, as well as the one in the NaK heat-rejection loop, were calibrated before installation. Water was utilized to calibrate the venturi used with liquids and air for the Hg vapor venturi.

Flow rates in the air system were obtained by sharp-edged orifice plates. Leakage rates of gaseous nitrogen in the cell inertion system were also determined by use of a sharp-edged orifice plate. Calibration of these orifice plates was not obtained because of the lack of available facilities with the capability to meter the flow rates involved accurately.

Strain-gage load cells. - Two load cells were used in the Hg system. One unit measured the weight of Hg in the expulsion tank, the other measured the weight of Hg in the standpipe. The use of both inputs was required to determine loop inventory.

Liquid-level indicators. - Liquid-level indicators were required in the primary and heat-rejection-loop expansion tanks during the filling process. Modified aircraft spark plugs were employed. Modifications to the spark plug included the removal of the ground electrode and the extension of the center electrode to the desired length by welding an extension rod to the center electrode. The low-level probes in both expansion tanks were set at approximately 1 inch (2.5 cm) from the bottom of the tanks, while the high-level probe was set at approximately 4 inches (10.2 cm) from the bottom of the tank. When the NaK made contact with the tip of the electrode, the electrode was grounded, illuminating a light on the control panel.

Vapor detector. - A commercially available eight-channel vapor detector unit, operating on the ultraviolet light absorption principle, checked samples piped from the facility and its coolant air exhaust lines. The detector unit was located beyond the outer containment wall. The detector continuously cycled through each of the eight channels checking each sample for Hg or NaK vapors. The reading of each channel could be recorded on a strip chart or could be observed on a scale on the front of the unit. Sampling stations were located in the cell proper, in each of the cooling air outlet pipes of the NaK to air heat exchanger, the Hg vapor to air heat exchanger, in each of the EM pump cooling air outlet pipes, in the cell scrubber outlet, and on the roof of the building.

Oxygen analyzer. - The oxygen analyzer, a commercially available dual range unit, was employed to monitor the oxygen content inside the test facility. The 0- to 10-percent range of the analyzer was connected to six stations within the inner enclosure; the 0- to 25-percent range was utilized for two stations outside the outer enclosure near the large entrance doors. A 16-percent minimum value was regarded as a safe level at the outer enclosure doorway. The oxygen content was recorded on a two-pen strip-chart recorder.

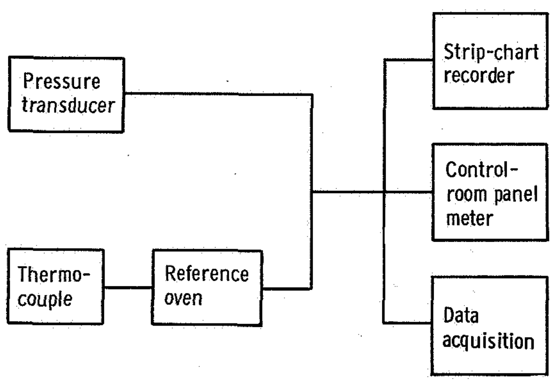


Figure 27. - Schematic drawing of loop instrumentation.

TABLE III. - INSTRUMENTATION LOCATION AND RANGES

(a) Temperature measurements

Parameter	Number of thermo-couples	ISA alloy (a)	Temperature range, °F	Temperature range, °K
Reactor simulator:				
Internal and shell	78	K	75 to 1300	297 to 977
Inlet	3	K	75 to 1130	297 to 883
Outlet	3	K	75 to 1300	297 to 977
Loop 1 EM pump (inlet, outlet, and coil temperature)	4	K	75 to 1130	297 to 883
Mercury boiler:				
Shell	94	K	75 to 1300	297 to 977
Inlet (NaK side)	2	↓	75 to 1300	297 to 977
Outlet (NaK side)	2	↓	75 to 1300	297 to 977
Inlet (Hg side)	6	↓	75 to 280	297 to 411
Outlet (Hg side)	8	↓	75 to 1300	297 to 977
Mercury vapor cooler (including air system)	36 1	J K	75 to 360 75 to 950	297 to 455 297 to 783
Mercury condenser:				
Internal and shell	85	K	75 to 800	297 to 700
Inlet (Hg side)	4	↓	75 to 800	297 to 700
Outlet (Hg side)	3	↓	75 to 800	297 to 700
Inlet (NaK side)	7	↓	75 to 450	297 to 505
Outlet (NaK side)	6	↓	75 to 625	297 to 603
Loop 2, Hg pump (inlet and outlet)	4	K	75 to 240	297 to 389

Parameter	Number of thermo-couples	ISA alloy (a)	Temperature range, °F	Temperature range, °K
NaK to air heat exchanger:				
NaK inlet, loop 3	3	K	---------	-----------
Internal, unit A, loop 3	24	↓	---------	-----------
Internal, unit B, loop 3	14	↓	---------	-----------
NaK outlet, loop 3	1	↓	---------	-----------
Units A and B, inlet and outlet, loop 3	84	J	---------	-----------
Loop 3, EM pump (inlet, outlet, and coil temperature)	3	K	---------	-----------
Loops 1, 3, and NPL EM flowmeter temperatures (5 units)	10	K	---------	-----------
Venturi temperature (loops 1, 2, and 3)	16	K	---------	-----------
NPL loop temperature	10	K	---------	-----------
Heated line temperatures (loops 1, 2, 3, and NPL)	44	K	---------	-----------
Pressure transducer body temperature at diaphragm (19 units)	19	K	---------	-----------
Miscellaneous:				
Cold-trap temperature (8 units)	8	T	75 to -320	297 to 77.6
Heater-element temperatures	6	R	75 to 2000	297 to 1366
Low temperatures	18	J	75 to 500	297 to 422
High temperatures	9	K	75 to 800	297 to 700

[a]Chromel-Alumel, type K; iron constantan, type J; copper-constantan, type T; platinum - platinum 13-percent rhodium, type R.

TABLE III. - Continued. INSTRUMENTATION LOCATION AND RANGES

(b) Pressure measurements

Parameter	Number of trans-ducers	Trans-ducer (b)	Pressure[c] range, psi	Pressure[c] range, N/cm²	Transient temperature operating range, °F	Transient temperature operating range, °K
Reactor simulator outlet	1	A	0 to 50	0 to 34.5	1300	977
Loop 1:						
EM pump inlet	1	A	0 to 50	0 to 34.5	1300	977
EM pump outlet	1	A	0 to 50	0 to 34.5	1300	977
Mercury boiler:						
Outlet	1	A	0 to 300	0 to 207	1300	977
	1	B				
Inlet	1	A	0 to 500	0 to 345	1300	977
	1	B				
Turbine simulator venturi inlet	1	A	0 to 300	0 to 207	1300	977
Turbine bypass venturi inlet	1	A	0 to 300	0 to 207	1300	977
Mercury condenser:						
Inlet	1	A	0 to 50	0 to 34.5	1300	977
	1	B				
Internal	1	A	0 to 50	0 to 34.5		
NaK outlet, loop 3	1	A	0 to 100	0 to 68.95		
NaK inlet, loop 3	1	A	0 to 100	0 to 68.95		
Mercury pump:						
Inlet	1	A	0 to 50	0 to 34.5	1300	977
	1	B				
Outlet	1	A	0 to 500	0 to 345	1300	977
	1	B				
NaK to air heat exchanger:						
Inlet, loop 3	1	A	0 to 100	0 to 68.95	1300	977
Unit A, loop 3, NaK upper manifold	1	A	0 to 100	0 to 68.95	1300	977
Unit A, loop 3, NaK lower manifold	1	A	0 to 100	0 to 68.95	1300	977
Loop 3:						
EM pump inlet	1	A	0 to 100	0 to 68.95	70 to 430	294 to 494
EM pump outlet	1	A	0 to 100	0 to 68.95	70 to 430	294 to 494
Mercury condenser ΔP	1	A	[d]0 to 20	[d]0 to 13.8	70 to 780	294 to 688
Venturi:						
Loop 1, flow ΔP	1	A	[d]0 to 20	[d]0 to 13.8	70 to 1300	294 to 977
Loop 2, flow at boiler inlet	1	A	[d]0 to 20	[d]0 to 13.8	70 to 280	294 to 410
	1	F				
Loop 3, flow	1	A	[d]0 to 20	[d]0 to 13.8	70 to 425	294 to 491
Mercury condenser exit ΔP	1	D	[d]0 to 10	[d]0 to 6.9	70 to 250	294 to 394
Loop 2, mercury vapor	2	D	[d]0 to 200	[d]0 to 138	70 to 250	294 to 394
Mercury condenser:						
Inlet (high frequency)	1	C	0 to 30	0 to 20.7	70 to 580	294 to 577
Outlet (high frequency)	1	C	0 to 30	0 to 20.7	70 to 450	294 to 505
Mercury vapor cooler inlet	1	B	0 to 400	0 to 276	70 to 1200	294 to 922
Liquid mercury supply venturis (3) ΔP	3	D	[d]0 to 500	[d]0 to 345	70 to 120	294 to 322
Mercury vapor cooler air inlet	1	D	0 to 50	0 to 34.5	60 to 90	288 to 305
NaK to air heat exchanger:						
Upstream air	2	D	0 to 50	0 to 34.5	60 to 90	288 to 305
Air orifice ΔP	2	D	[d]0 to 30	[d]0 to 20.7	60 to 90	288 to 305
Miscellaneous nitrogen and argon gas system	11	E	70 to 3000	0 to 2070	70 to 125	294 to 324

[b]Slack diaphragm with capillary, A; slack bellows, B; strain gage, C; variable reluctance, D; servo, E; direct-reading Bourdon gage, F.
[c]All pressures are absolute unless otherwise noted.
[d]Differential pressure.

TABLE III. - Concluded. INSTRUMENTATION

LOCATION AND RANGES

(c) Miscellaneous measurements

Parameter	Quantity	Range
Flow, EM flowmeters, loops 1, 2, 3, and NPL	5	0 to 6000 lb/hr (0 to 0.72 kg/sec)
Master time clock (recording correlation) 3 channels	1	sec to min
Valve position indication	8	-----------
Weight, mercury standpipe and expulsion tank	2	-----------
Reactor simulator input electrical power	1	0 to 650 kW 0 to 65 mV
Analog computer power signal to reactor simulator	1	0 to 650 kW 0 to 50 mV

Pressure instrumentation. - All the pressure transducer locations and ranges are shown in table III. A schematic drawing of transducers and their readouts is shown in figure 27.

Before being installed in the system, all the transducers were calibrated over a range of environmental temperatures from room temperature to slightly above operational temperature. A calibration check was then made before each test and immediately after shutdown at room temperature by using the argon cover gas.

Temperature instrumentation. - All thermocouples (see table III and fig. 27) used to obtain liquid metal temperatures were Chromel-Alumel in an AISI 316 stainless sheath. All the thermocouples were referenced to 150° F (339° K).

NaK axial temperature profiles in the electric heater were obtained by immersion and outer shell surface thermocouples. The imersion thermocouples were passed through projection tubes welded to the bottom plate of the heater, through the inlet plenum chamber, and into tubes that were used to form flow passages for the NaK.

Slots in the flow passage tubes were cut at the desired location. Internal flow passage tubes, through which thermocouples were passed to measure outlet plenum chamber temperature, were not slotted.

The measurements obtained in the outlet plenum chamber were used to determine simulated temperatures of a nuclear reactor upper grid plate, required by the analog

computer of the reactor simulator controls. Thermocouples were installed in the lower grid plate of the first heater design. These thermocouples were brought out of the heater through the wall and through tubes welded to the wall. All the immersion as well as the simulated lower grid plate thermocouples were sealed by compression fittings.

The immersion thermocouples used in the NaK heater were constructed of spiraled twisted conductors, at least one turn per inch (2.5 cm), to reduce the alternating-current pickup from the heating elements of the heaters.

Immersion thermocouples were also installed axially through the wall of the condenser into the NaK passageway to determine Hg condensing length. Sheathed, untwisted thermocouples were passed through compression fittings welded to the condenser shell.

Two immersion thermocouples located at the boiler outlet were used in determining the quality of the Hg vapor. The two thermocouples were located through the top of the outlet tube 90° from one another; one facing upstream 45° to the top wall, the other facing downstream 45° to the top wall.

Use of the immersion thermocouples in the liquid metal loops was minimized because of the leakage potential involved. All tubing temperatures were measured by surface thermocouples.

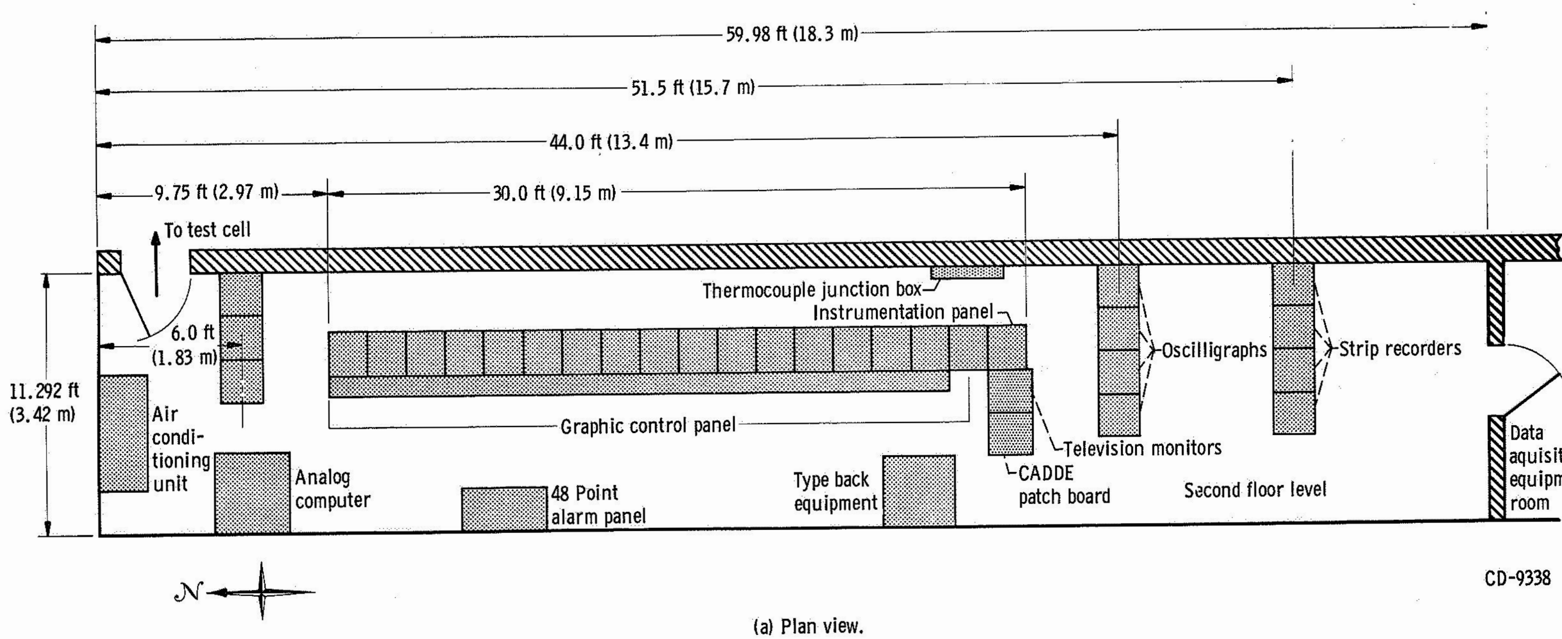
Thermocouples were attached to the laminated bus bars of the EM pumps. These thermocouples were used as a means of monitoring pump coil temperatures; temperatures limitation of the laminations was set at 650° F (616° K). Temperatures of the magnets of the EM flowmeters were monitored by use of the sheathed, spirally twisted Chromel-Alumel thermocouples. Excessive heat at the magnets was conducive to erroneous readouts of flow measurements.

Television

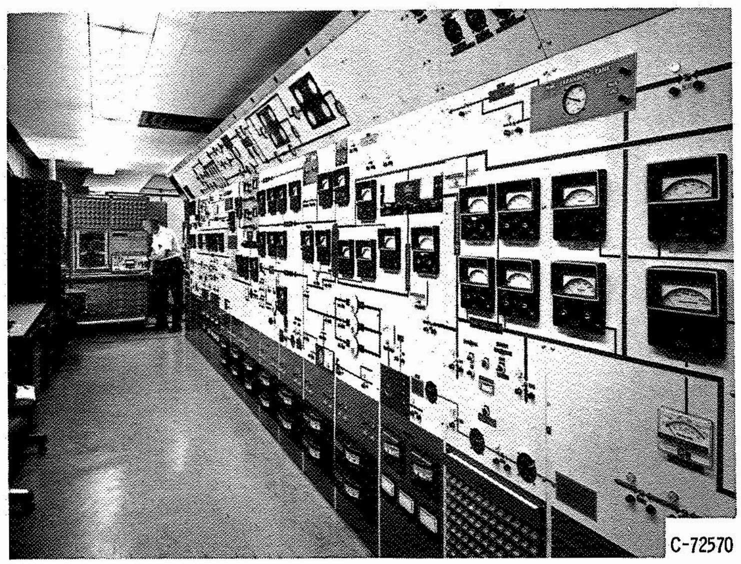
Two television cameras were utilized to observe any portion of the facility while the loops were operating. One camera was located near the primary loop dump and fill lines, the other near the Hg to coolant oil heat exchanger.

Control Room

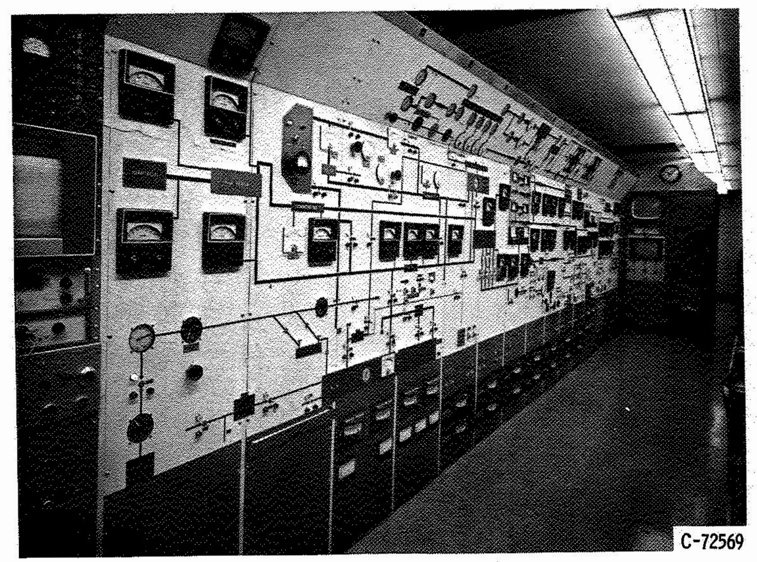
A plan view and photographs of the control room are presented in figure 28. The control room was remotely located from the test facility and was on the second floor level. Communication with personnel in the facility enclosure was possible by either a telephone or intercom system. Movement of personnel within the cell, as well as any part of the facility, could be observed in the control room by two television monitors.



(a) Plan view.



(b) Computer console.



(c) Control panel.

Figure 28. - Control room.

Instrumentation output signals were sent from instrumentation panels located near the test facility by an interconnect system to instrumentation panels located near the east wall of the control room (see fig. 28(a)). From the control-room instrumentation panels, the output signal could be sent to panel meters, to the analog computer, to strip recorders, to oscillographs, to the Lewis Central Automatic Data Digital Encoder (CADDE, ref. 5), or to a combination of these by amplifying the output signal when necessary. Playback of any number of outputs, in digital form, could be obtained immediately after the data were taken.

The facility piping was displayed graphically in 17-rack panels. Valves and components with their controls and instrumentation meters were located in the same sequence on the panels as they were in the actual loops in an attempt to minimize the chances for error in the facility operation.

Meters for use in the control panel were purchased with relays for adjustable set points for low and high limits. Visible and audible alarms were wired to the relays of meters monitoring parameters considered critical to loop operation.

OPERATING PROCEDURES

Liquid Metal Loop Operation

All instrumentation was calibrated prior to filling the liquid metal loops. The pressure pickups were checked by pressurizing the systems with argon. A vacuum was then pulled on all loops. Vacuum pressures were of the order of 15 to 20 torr (2000 to 2670 N/m^2). The facility was inerted with gaseous nitrogen after the required vacuum levels were obtained.

The two NaK loops were filled and brought to operating conditions prior to operation of the Hg loop. The NaK loops were filled by pressurizing the NaK dump tank to a pressure of 10 to 18 psia (6.90 to 12.40 N/cm^2 abs) with argon. The operation continued until NaK was indicated to be in both NaK loop expansion tanks. The dump tank was then valved off. The loops were pressurized to 40 psia (27.6 N/cm^2 abs) with argon through the expansion tanks and valved off for 1 hour to check for leaks. After the pressure check, the power to the line heaters on the heat-rejection loop, the transfer lines, and on the NPL loop were activated to preheat the loops to approximately 300° F (422° K). The primary loop was heated convectively to approximately 300° F (422° K) in steps of 100° per hour by the NaK electric heater. The primary loop expansion tank and its expansion line were also heated with the circular line heaters. At 300° F (422° K), power was applied to the NaK pumps and heating was continued to nominal operating temperatures.

While the loops were heated to temperatures above 300° F (422° K), the oxide content of both loops was checked; cold trapping to remove oxides was performed when required. NaK would be circulated through the piping at operating temperatures and then dumped hot into the dump tank if any portion of the piping had been exposed to the atmosphere before the test. Oxides would precipitate in the dump tank as the NaK cooled. When the system was refilled only clean filtered NaK went into the system. The hot flush procedure cleaned the piping of the gross amount of oxides in less time than would be required for the equivalent amount of cold trapping.

After the NaK loops reached their nominal operating conditions, the Hg was charged into the evacuated liquid portion of the Hg loop from the expulsion tank. Gas pressure in the expulsion tank was approximately 150 psia (103.5 N/cm^2 abs). The Hg loop was filled to the boiler-inlet control valve and to the condenser outlet valve. The standpipe was also filled to a predetermined level. When filling was completed, the Hg pump was started with the boiler inlet, pump outlet, and pump bypass control valves opened. The pump bypass valve was slowly closed while adjustments were made to the pump-outlet and boiler-inlet valves. With the pump bypass valve fully closed, the desired conditions at the boiler inlet were obtained. The right-angle control valves at the boiler outlet were positioned to obtain the desired boiler-outlet pressure. Mercury inventory was controlled by flowing Hg from or to the standpipe.

The heat-rejection-loop NaK flow to the condenser was adjusted by the three-way valve to obtain the proper condenser-outlet conditions. Coolant airflow to the NaK to air heat exchangers was regulated to provide the required condenser inlet temperature.

A heat balance across the boiler was made with every data point to obtain a measurement of the quality of the Hg vapor at the boiler outlet and compared with the ratio of vapor to liquid flow rates.

Entry of Inerted Facility

During loop operation, it was often necessary to enter the inner enclosure while inerted for minor repairs or checks. Personnel entering the inner enclosure were provided with a chromium leather helmet that had a form-fitting apron draping the chest, back, and shoulders of the wearer. Attached to the helmet was an intercom set and a hose with pressure regulated filtered breathing air. The intercom and the hose as well as a stainless-steel cable were attached to a waist belt worn over a chromium leather coat. Personnel also wore rubber foot wear as well as spats to protect the ankles and shoe tops.

Loop operating conditions were reduced to a minimum standard before entrance to the inner enclosure was made. A buddy system was employed: two men entered the cell, one man serving as the worker, the other as an observer. A third man was stationed

outside the outer enclosure in the event of an emergency. Constant communication was kept between the three men as well as with personnel in the control room. Movement of the personnel in the inner enclosure was observed by personnel in the control room by television monitors.

DISCUSSION OF RESULTS

Running time accumulated on the three liquid metal loops as a system was 975 hours. Additional running times accumulated on the primary NaK and heat-rejection loops were approximately 960 and 990 hours, respectively. The additional time on the two NaK loops was obtained in conducting hot flush runs, cold trapping and oxide runs, and performance tests on the pumps and the loops in general. The system was operated at nominal operating pressures and temperatures with loop flow rates exceeding the design values (36 000 lb/hr (4.54 kg/sec) in both NaK loops and 10 250 lb/hr (1.29 kg/sec) in the Hg loop with an electrical power input to the NaK heater of 475 kW) until EM pump trouble limited the flow. Two series of tests were performed; one for steady-state data where system nominal temperatures and pressures were maintained at Hg flow rates of 7600 pounds per hour (0.96 kg/sec) and NaK flow rates of approximately 32 000 pounds per hour (4.04 kg/sec) with NaK heater power input of 350 kilowatts; the second for a series of startup techniques of the Hg loop where the system nominal pressures and temperatures were obtained at Hg flow rates up to 9200 pounds per hour (1.16 kg/sec) and the NaK flow rates of approximately 32 000 pounds per hour (4.04 kg/sec) with a NaK heater power input of 420 kilowatts.

Temperatures in the loops of the system were cycled many times during the course of operation. A temperature history of each loop is presented in figure 29. Trouble was experienced with system components and test support equipment while the test was being conducted. These problem areas are presented in the following paragraphs.

NaK Electric Heater

The original NaK electrical heater in the primary loop was operated for 1037 hours before it was removed from the system because of heating-element failure and NaK leakage through the heater elements. This heater was in operation approximately 375 hours at an output of 380 kilowatts

We believe that the heater failure originated with an electrical short from at least one of the heating-element lead wires across the staybars on the top of the heater. It is speculated that the arcing across the staybars increased to such an extent that the layer

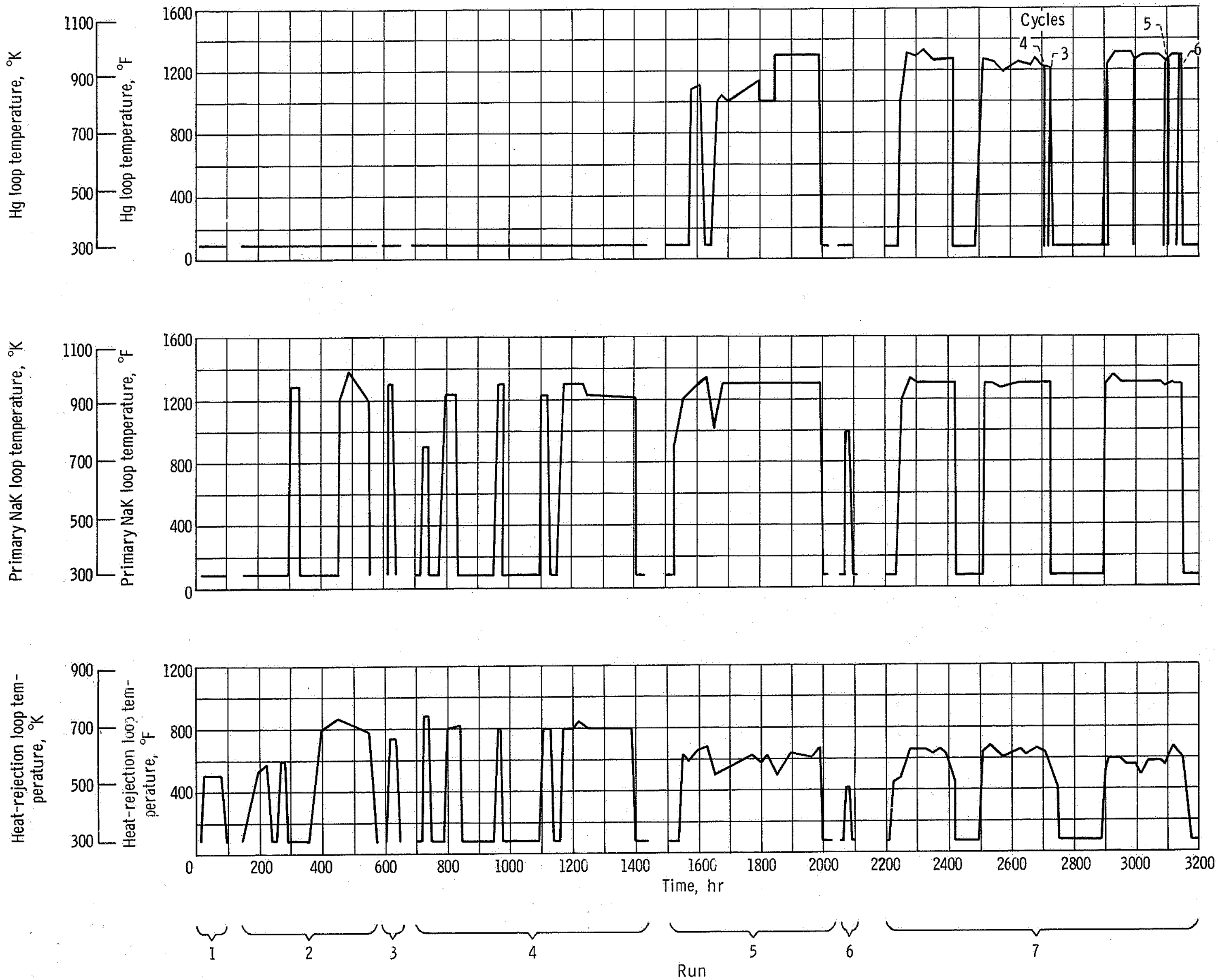


Figure 29. - Temperature history of system loops.

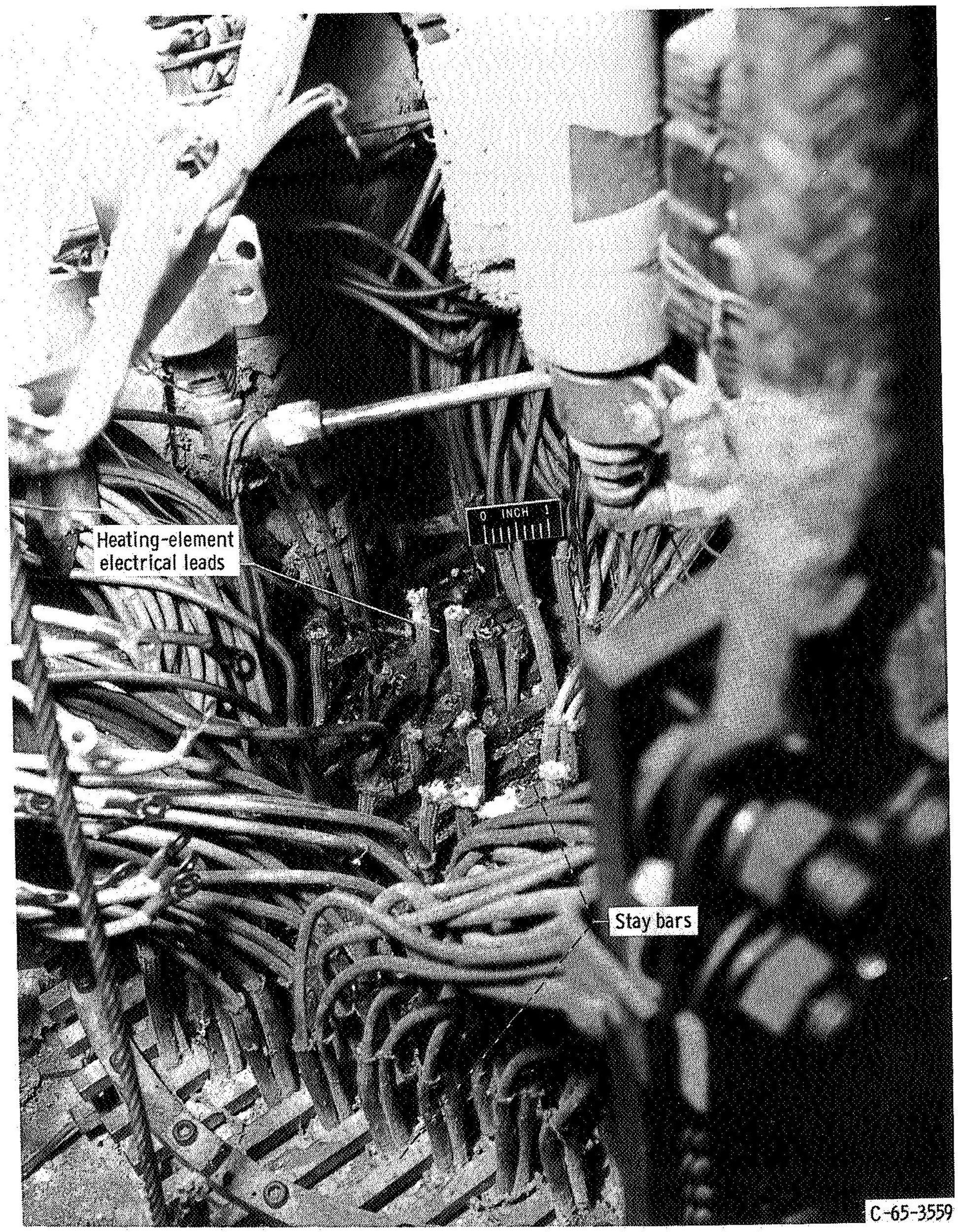
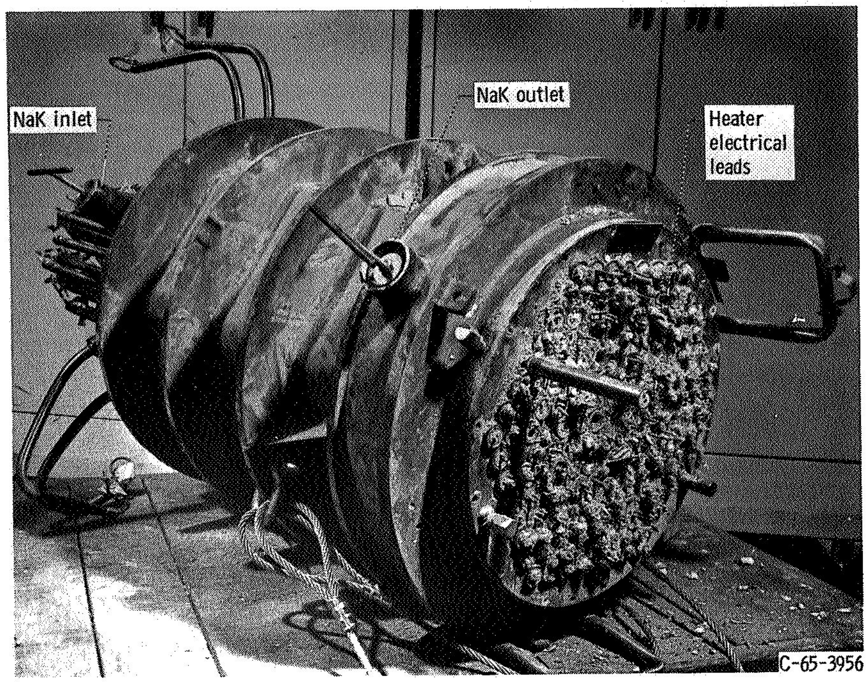


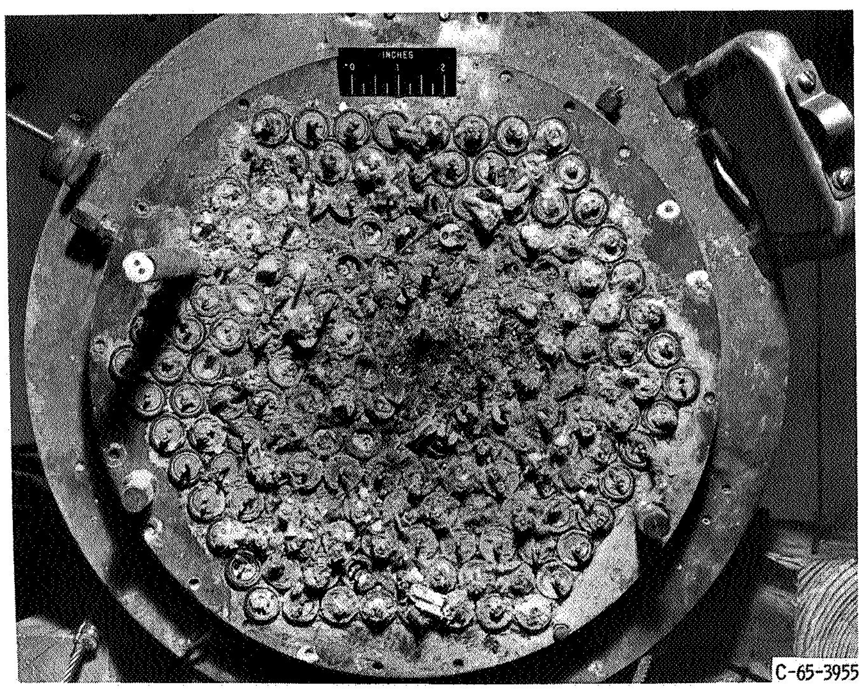
Figure 30. - Top of NaK heater after power failure.

of gas above the component was ionized. Some staybars were melted, while others became welded to the shell of the component. Fifty pairs of heating-element lead wires were burned off (see fig. 30). All electrical power in the facility failed at the time of the heater failure.

An attempt was made to restore the unit. One failed element was successfully replaced, but a second replacement could be forced only half way into its well. Replacement of heating elements was abandoned in favor of connecting electrical leads to the stub ends of lead wire of the remaining sound heaters. Staybars were eliminated, and fuses



(a) Overall view.



(b) Top view.

Figure 31. - Damaged NaK electric heater.

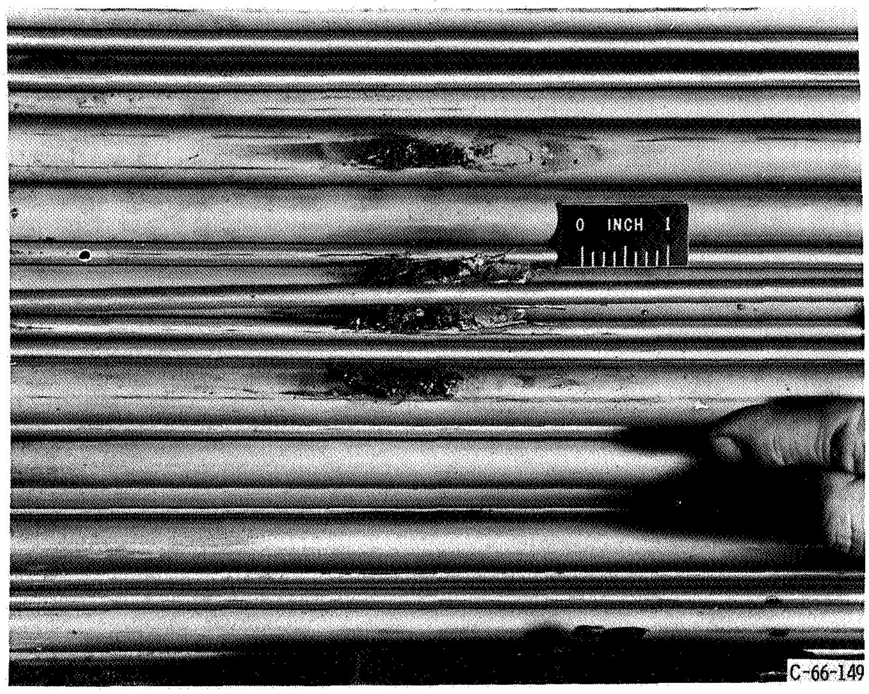


Figure 32. - Damaged heater-elements wells.

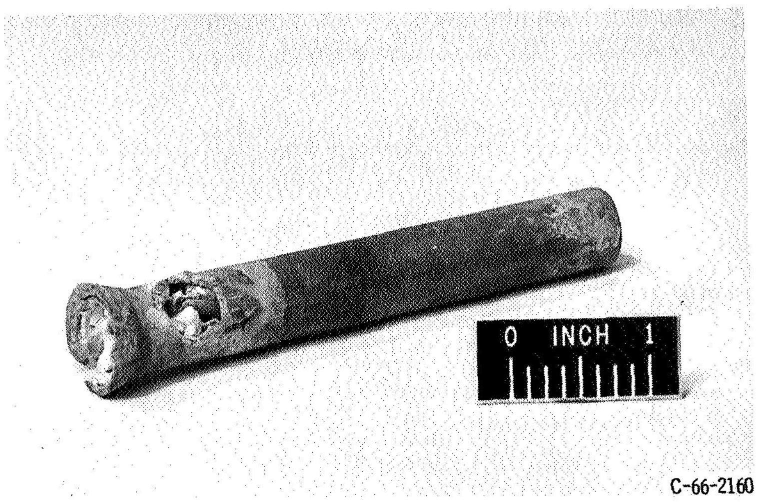


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Figure 33. - Damaged heater element.

were placed into the wiring system, one pair of fuses per pair of heating elements connected in series.

Startup of the primary loop was attempted with 152 active heating elements in the heater component. At a power output of 13.5 kilowatts, fuses began to blow, and an indication of a NaK leak at the top of the heater was noted. The heater was replaced with its backup unit.

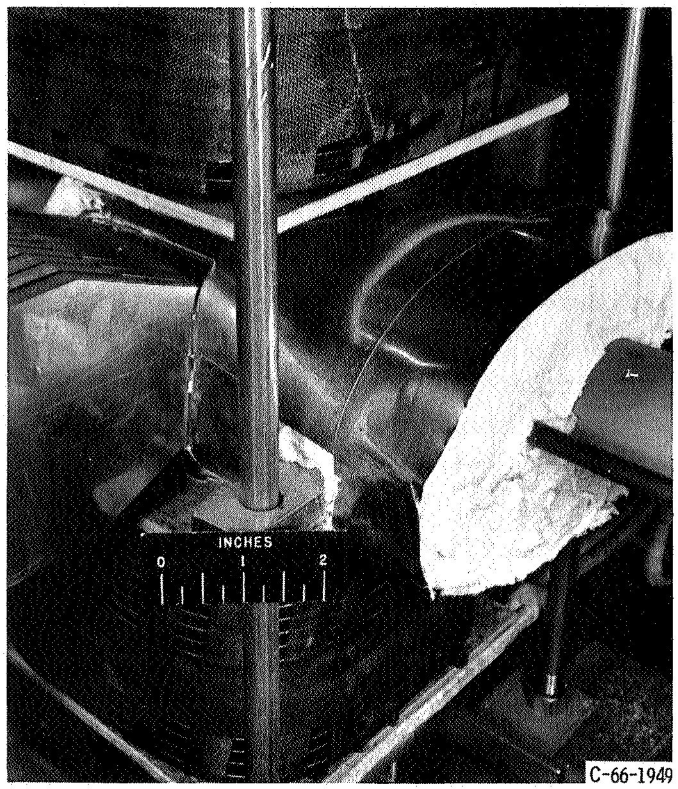
Photographs of the damaged heater component after it was removed from the system are shown in figure 31. Burnthrough of the heater wells and the heater element is shown in figures 32 and 33.

After the backup electric heater was installed, a test was initiated to determine the heating-element sheath-wall thickness that could absorb a shorting of the element without causing a burnthrough. Results indicated that an electric shorting of the element wire would not burn through a 0.090-inch (2.3-mm) wall sheath. For the next heater design, it was recommended that the heating-element well be eliminated and the element be placed directly into the NaK to obtain lower element wire temperature and that the sheath-wall thickness be increased from 0.032 to 0.090 inch (0.8 to 2.3 mm) for prevention of electrical burnthrough. Fuses on each pair of heating elements would provide additional safety and added life to the heater.

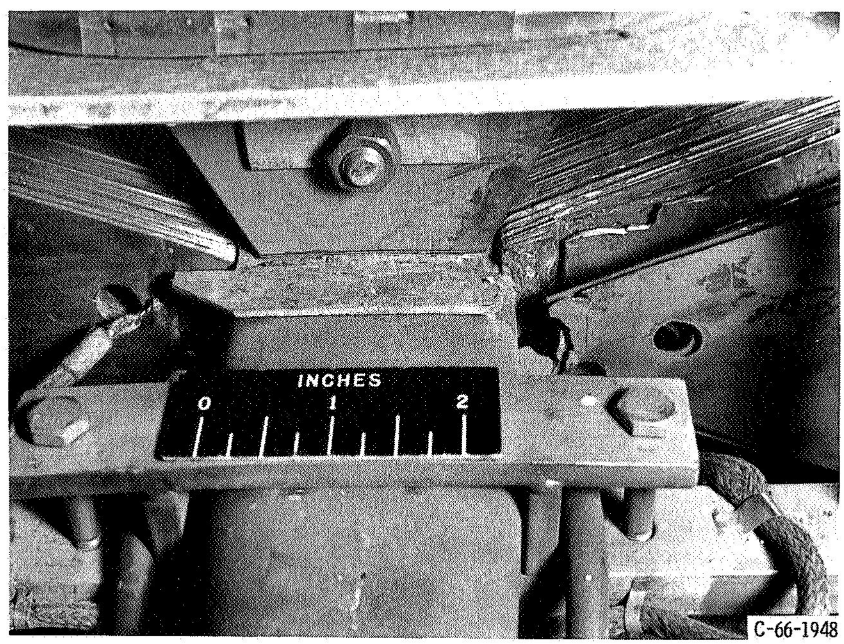
Electromagnetic Pumps

Before testing with the Hg loop in the system was accomplished, operational difficulties were encountered with the EM pumps. After 640 and 850 hours of operation of the primary and heat-rejection loops, respectively, at a given power input to the pumps, increasing amounts of air were required to cool the laminated bus bars. With progressing time, at the same power input to the primary-loop pump, the NaK flow rate decreased, indicating a loss in pump efficiency. After 945 hours of primary loop operation, four of the eight fuses on the pump variable autotransformer were blown. The fuses were replaced and the primary-loop pump restarted with the recommendation to operate at lower power inputs and lower flow rates. After 1445 hours of operation, the fuses at the autotransformer again blew. They were replaced with larger load fuses (from 30 to 35 A). The use of larger fuses, allowed an increase of pump power input and flow rates. After approximately 46 hours of operation at the higher flow rates, the pump failed as the result of burnout of three of the eight-gang autotransformers. These were replaced, and the remainder of the test was conducted at reduced primary flow rates.

Examination of the pump after testing revealed severe damage to the laminated nickel bus bars. Evidence of arcing existed (fig. 34) No evidence of damage to the pump cells was noted.



(a) Before test.



(b) After test.

Figure 34. - Primary-loop electromagnetic pump.

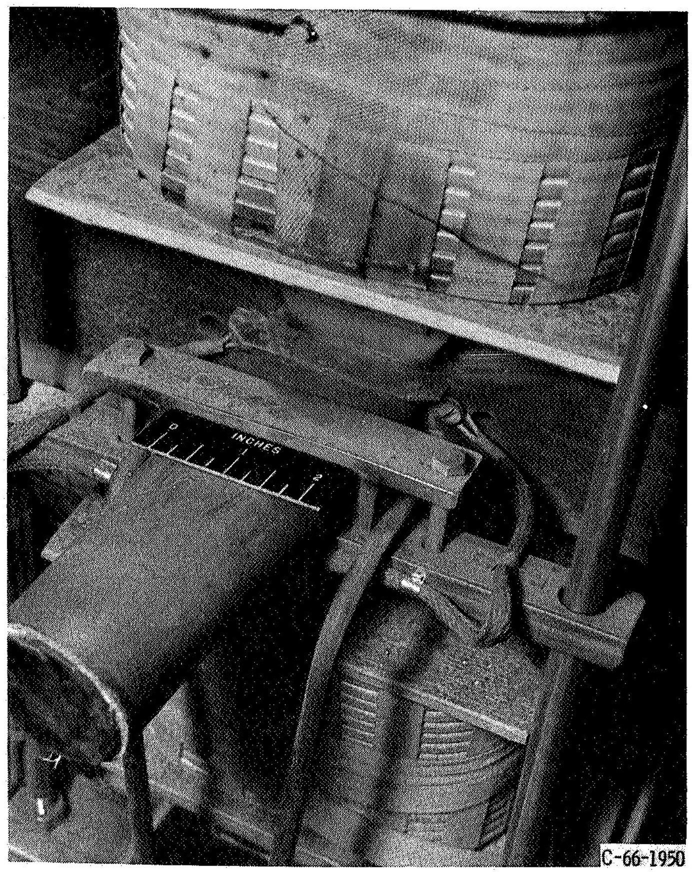


Figure 35. - Heat-rejection-loop electromagnetic pump after test.

Similar problems were enountered with the heat-rejection-loop pump. No attempts were made to run the pump at high flow rates by using larger fuses. Flow rates were limited to the rate which did not overload the power supply. A photograph of the heat-rejection-loop pump after completion of the test is shown in figure 35.

Mercury Preheater

The preheater at the boiler inlet failed because of the malfunctioning of the heating-element temperature-control unit for two of the four preheater units. The remaining two preheater units did not have the capacity to increase the temperature of the liquid Hg from 300° to 500° F (422° to 533° K), as required.

Valves

In the NaK loops, two valves in the transfer lines, one in the oxide control loop, and one in the line from the primary loop high point at the boiler inlet to the expansion tank,

were replaced because of external leakage across the valve stem bellows seals. Two of the valves were removed after 461 hours of service, and the other two after 767 hours.

The dump and fill valve located near the primary process piping had a slow internal leak across the seat; however, its backup valve did not leak. Therefore, it was not necessary to remove the leaking dump and fill valve.

In the heat-rejection-loop condenser bypass line, the shutoff valve, on actuation to the open position failed to travel to its fully opened position. The cause was a bent valve stem. After 1255 hours of service, the pneumatic operator of the valve was removed, the travel of the valve was set to its fully opened position, and the stem was welded to the valve body to maintain the fully open position.

After 540 hours of Hg loop operation, one of the right-angle control valves at the boiler outlet developed an external leak across its bellows seal. The second right-angle valve at the boiler outlet and its backup valve at the Hg vapor cooler inlet developed external leaks across the bellows seal after 750 hours of service. The operators of these valves were removed and the stems welded so that the valves were in the fully opened position. Weldment of the stem to the valve bonnet eliminated the external Hg vapor leakage.

Mercury Pump

The Hg pump after 544 hours of operation was removed from the loop to replace bearings. The pump running load had increased from 21.5 to 22.5 amperes indicating bearing wear. After replacement of bearings, a running load on the pump of 21.5 amperes was obtained.

Liquid-Level Probes

The aircraft spark plugs used to indicate the level of NaK in the expansion tanks were mounted through machined adapters welded to the top of the tanks. During the NaK loop fill process, NaK was splashed to the top of the tank, filling the small plug-to-adapter wall gap causing a false level indication. Removal of the oxide with an argon purge in the tank was never entirely successful. Use of a glass to metal tubing as a sleeve around a coiled wire connecting the center electrode to the extension rod isolated the center electrode from the NaK oxide buildup for only short periods of time as a result of the breakdown of the bonding material between the glass and metal.

The problem associated with the false level indications was attributed to improper design of the expansion tank. The incorporation of a splash plate over the NaK inlet tube, the use of larger gaps between the plug and inner wall of the adapters, and locating the level indicators at the tank end opposite the inlet tube could have avoided this problem.

Hydraulic System

The hydraulic operator for the three-way condenser bypass valve in the heat-rejection loop was removed after 757 hours of loop operation because of leakage of hydraulic fluid. The hydraulic operators on the boiler-inlet Hg flow-control valve and on the two right-angle valves at the Hg boiler outlet were also checked for leakage. Leakage was found at the boiler-inlet Hg flow-control valve, and therefore its operator was also removed. Dismantling of the hydraulic operators and their servovalve mechanism indicated badly worn butyl O-rings. At the time of purchase of the hydraulic operators, butyl was the only composition known to be compatible with the phosphate ester base hydraulic fluid. Since then, ethylene-propylene was found to be a better material. The loss of the hydraulic operators meant a reduction in the dynamic testing.

Cold Traps and Associated Hardware

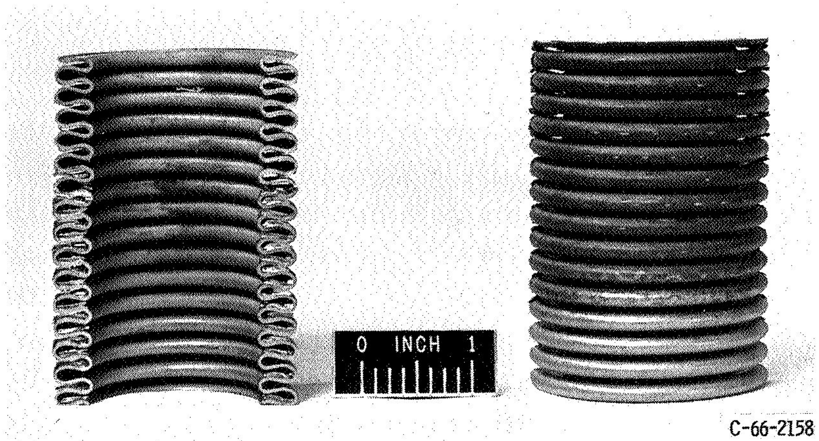
Each gas supply vent and vacuum line connected to the liquid metal loop piping was routed through cold traps at temperatures of approximately -60° F (222° K). Either the cold traps or lines connecting them to the NaK loops would on occasion become plugged. At the end of the particular test, either the cold traps were heated to remove the plug or the cold trap was replaced. We believed that the plugging occurred because of operational procedures. Changes in loop pressure level were made too rapidly. The use of deflector plates in collectors near the NaK process lines and at the expansion tanks may also have helped to avoid this problem.

Pressure Transducers

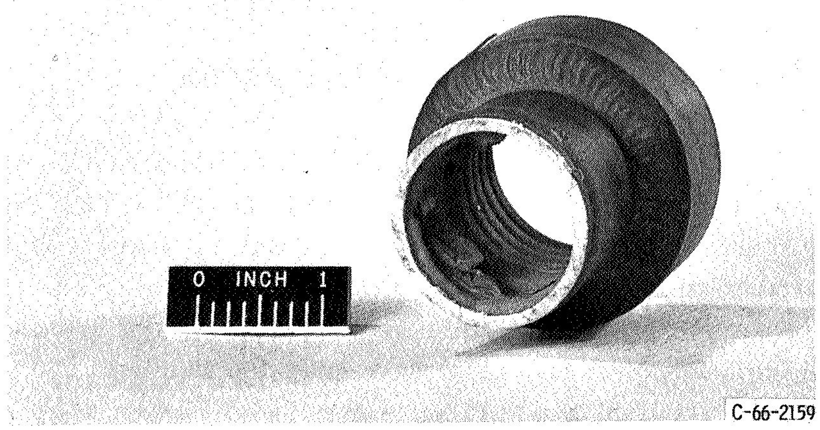
Of the 29 transducers in contact with liquid metals, one failed during the test. A small leak across the thin diaphragm occurred in the transducer located at the outlet of the boiler on the Hg side. The failed transducer was replaced.

After approximately 2000 and 1000 hours of operation of the NaK loops and Hg loop, respectively, tests on the system were terminated, and the system was disassembled. The components and test support equipment not required for the next phase of testing were examined.

No flexible hose rupture nor weldment leaks occurred during the tests. Sections of the hose located between the outlet and the primary loop pump and the dump line are shown in figure 36. This hose was located in the most severe environment of any of the hoses in the NaK loops; not only was the temperature level highest (1300° F (977° K) dur-



(a) Bellows section.

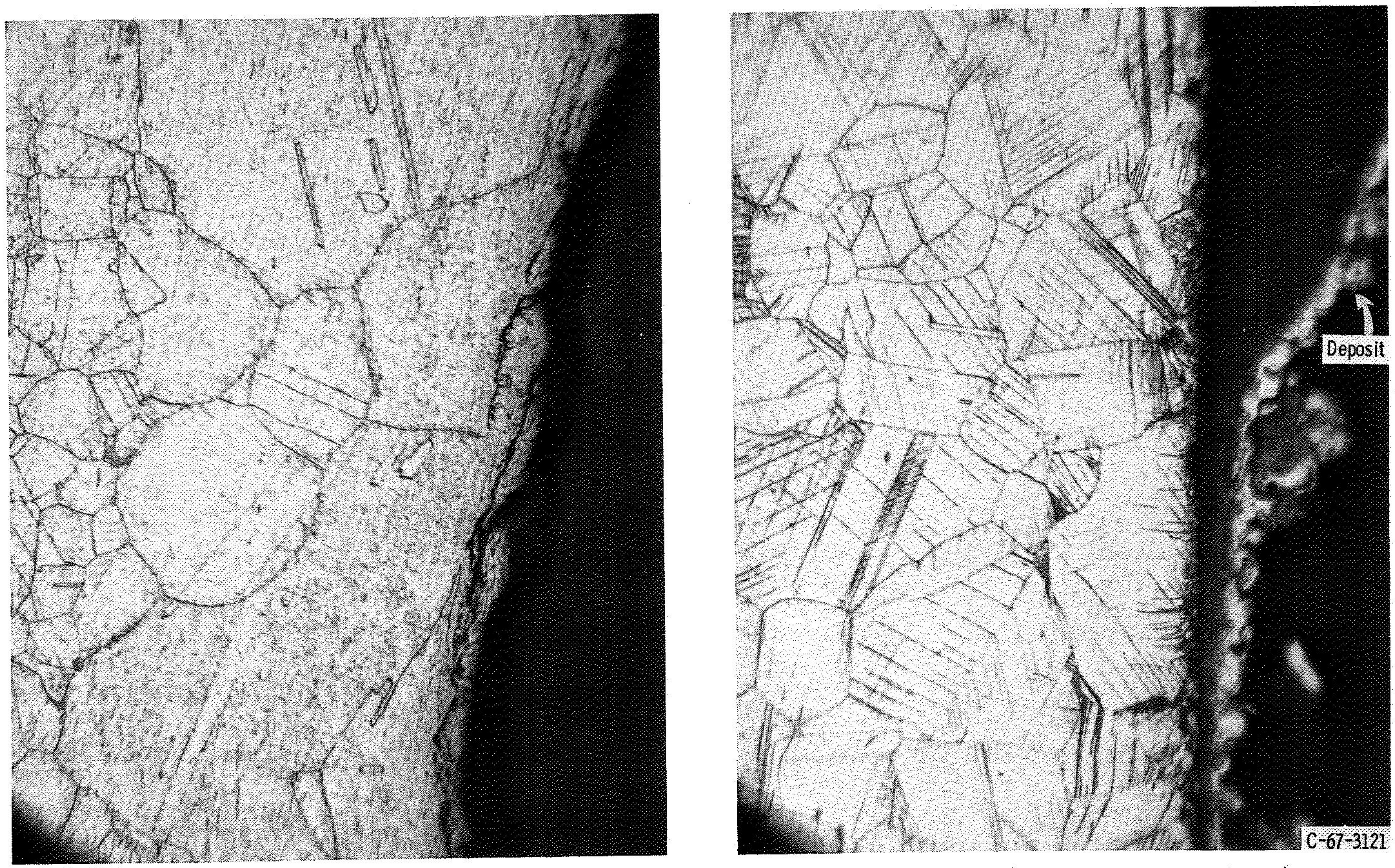


(b) Tube connector.

Figure 36. - Flexible hose.

ing hot flush runs) but it was also located in the region through which NaK and any of its impurities from the loop would settle during the dump process. During normal loop operation, its temperature was 1100° F (866° K). Wall thickness of the bellows area was reduced 0.0005 inch (0.00127 mm) indicating some leaching effect by the NaK. Deposits can be observed in the photographs of figures 36(a) and (b). A 0.004-inch- (0.0102-mm) thick film of chromium and iron content was deposited in the flexible hose section. Photomicrographs of the connector end of the flexible hose and its adjoining transition piece are presented in figure 37. Grain size of the transition piece was smaller than that of the flexible-hose connector end. The film deposit partly lifted away from the surface of the transition piece is shown in figure 37(b).

The Hg vapor venturis in the turbine simulator were removed and recalibrated with air. A comparison of the calibrations of the two venturis before and after testing are



(a) Flexible-hose connector end.

(b) Transition piece welded to flexible-hose connector end.

Figure 37. - Photomicrograph of flexible-hose connector end. X125.

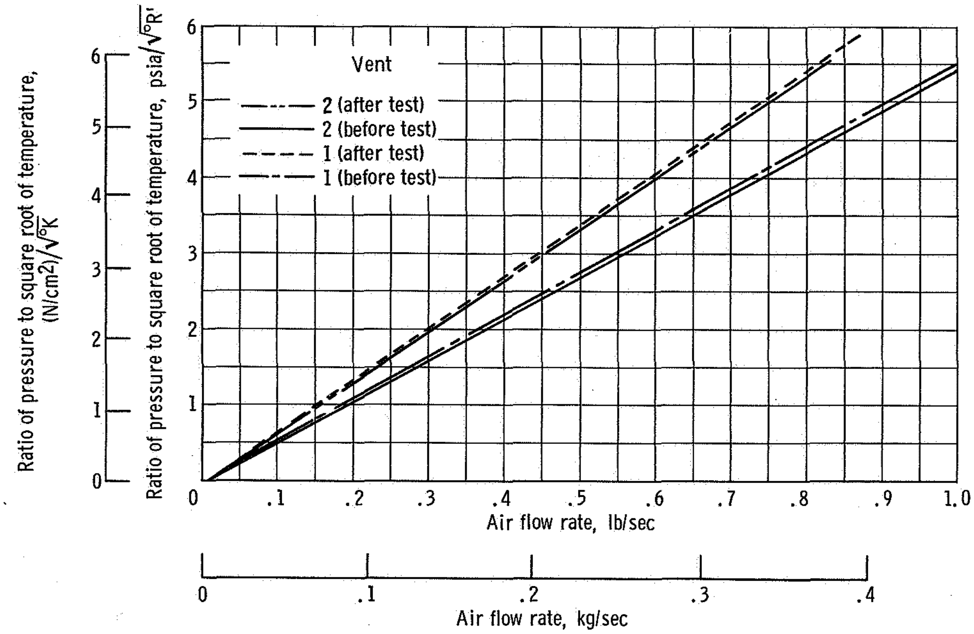
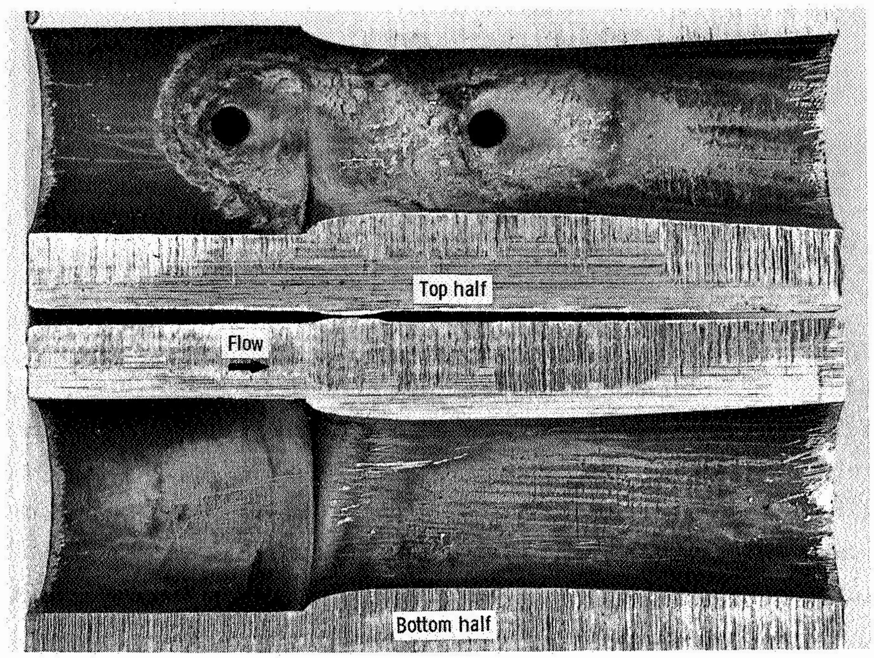


Figure 38. - Comparison of air flow calibration of turbine simulator venturis before and after test.

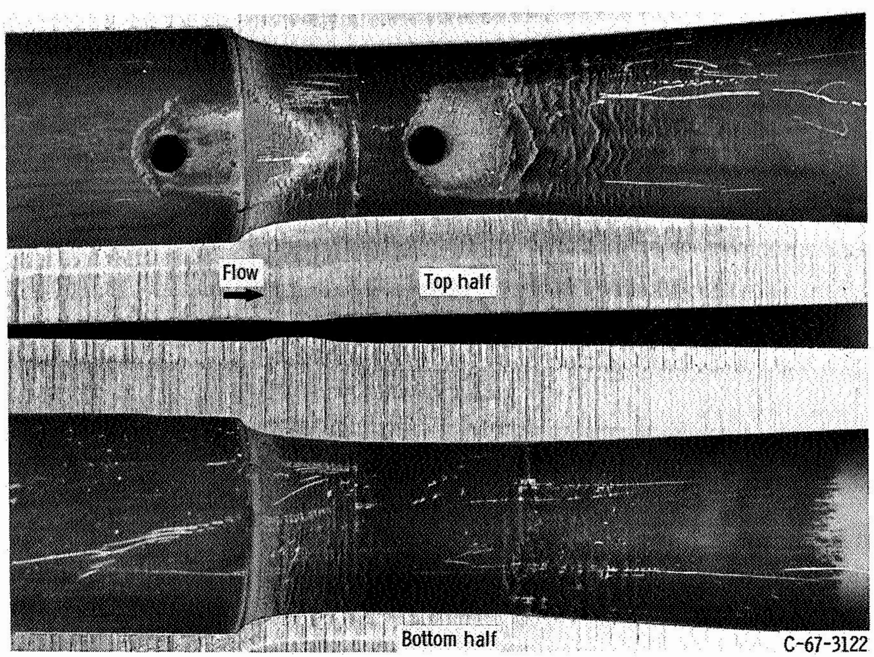
shown in figure 38. Results indicate a large discrepancy in flow rates for both venturis. After test calibrations indicate approximately 20 percent lower flow rates at a pressure-temperature ratio ($P/\sqrt{T}$) of 5.1. Examination of the photomicrographs of the venturi presented in figure 39 show severe eroding and/or corroding of the top side of the venturi, especially the number 1 venturi (fig. 39(a)) through which most of the Hg vapor flow rate was metered. A large portion of the entrance section to the throat, as well as the throat section of the number 1 venturi, was eroded away by the Hg vapor. Erosion, as well as corrosion, about the holes utilized as pressure taps of both venturis was evident. The throat sections were so badly corroded and/or eroded that obtaining average throat diameters were futile.

The liquid Hg venturi at the boiler inlet was also recalibrated after the test was terminated. Water was employed as the calibrating fluid. A comparison of the results of before and after testing is presented in figure 40. For the Reynolds number range of 6×10^4 and higher, the water flow rates increased about 1.8 percent as a result of the increase in discharge coefficient from 0.982 to 1.00. The throat diameter was increased from 0.2008 to 0.2020 inch (0.508 to 0.5107 cm). The overall increase in flow rate due to the change in throat diameter and discharge coefficient was approximately 1.9 percent.

The erosion and/or corrosion effects on the entrance section to the venturi throat could have been avoided by either fabricating the venturi with a refractory type metal such as tantalum rather than AISI 316 stainless steel or by using a longer, gradually sloped entrance section rather than a bell mouth shaped entrance.



(a) Venturi 1.



(b) Venturi 2.

Figure 39. - Photomicrograph of turbine simulator venturi. X3.

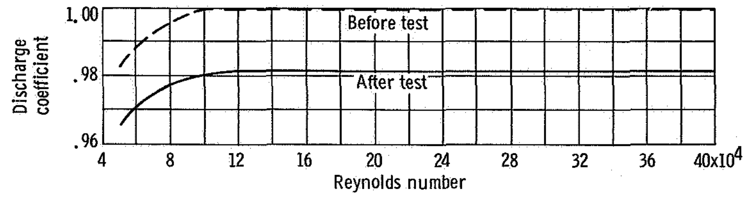


Figure 40. - Comparison of water flow calibration before and after test of liquid mercury boiler inlet venturi.

CONCLUDING REMARKS

A simulation of the SNAP-8 system that was designed, assembled, and tested was capable of flow rates of 32 000, 9100, and 32 000 pounds per hour (4.04, 1.15, and 4.04 kg/sec) in the NaK primary loop, the Hg working loop, and the NaK heat-rejection loop, respectively. An electric heater in conjunction with an analog computer was designed to simulate the nuclear reactor in the SNAP-8 primary loop. Valves, venturis, and a Hg to air heat exchanger were employed to simulate the pressure and temperature drop across a turbine. NaK to air heat exchangers in conjunction with controlled cooling air and the analog computer simulated a radiator.

Each NaK loop and the Hg loop were operated for approximately 2000 and 1000 hours, respectively, through numerous temperature cycles. Results of the tests indicated that flexible hoses installed to accommodate thermal expansion of system piping by lateral movement can be safely employed in a liquid metal system. Unbaffled gas and vacuum lines connected to expansion tanks can become plugged. Baffling and location of these lines with respect to liquid metal inlet lines should be considered in the design of the expansion tanks. The location of spark-plug liquid-level indicators with respect to liquid metal inlet lines to expansion tanks to prevent splashing is also important. The heater design should eliminate the use of heating-element wells to ensure lower heating-element wire temperatures by direct immersion into the liquid metal. Heavier sheath walls for the heating elements provides additional safety against an electrical burnout, especially if the heating elements are fused, and also provides a suitable heater wall thickness for welding the heater elements to a header plate.

Erosion and/or corrosion of the entrance and throat sections of choked mercury venturi resulted in inaccuracies in flow measurements. We believe making the venturi with refractory material such as tantalum or a longer, gradually sloped transition section to the throat could result in a more reliable venturi design.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 28, 1967,
701-04-00-02-22.

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